A Three-Season Analysis of Positional Demands in Elite English Rugby Union

Thesis submitted in accordance with the requirements of the University of Chester for the degree of Doctor of Philosophy

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August 2014

Declaration of Originality

This work is original and has not been previously submitted in support of a Degree, qualification or other course.

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Acknowledgements

I would like to thank enormously my supervisory team Dr Paul Worsfold, Professor Kevin Lamb, Dr Jamie Highton, Roy Headey and Stafford Murray for their expert advice, assistance and continual support and guidance on the present thesis over the last four years, it has been greatly appreciated. I would also like to extend my thanks to other members of faculty staff and PhD students who have offered invaluable advice, support and guidance over this period.

I would like to thank the Rugby Football Union (RFU) and the English Institute of Sport for their funding and support over the last four years, particularly Roy Headey, Stafford Murray, Ben Pollard and Ruth Hibbis-Butler for all their help.

I would to extend my thanks to Premiership Rugby, in particularly Corin Palmer and Phil Winstanley for their help to make the process of recruiting premiership clubs as easy as possible. I would also like to sincerely thank all the participating clubs and practitioners I have worked with over the last four years for their co-operation.

Lastly my biggest thanks go to my husband Tom for his unwavering patience, love and encouragement and all of my immediate and extended family and friends, particularly Mum Dad, Donna, Phil, Amanda, Stephen, Michaela, Mike, Declan, Siobhan, Grace, Kitty-Ann, Leo, Enya, Evelyn, Clare, Kevin, Sarah, Hannah, John, Natalie, Rachel, Sarah and Clare for all their love and help and again patience with me over this time, I couldn't have done it without you all.

Abstract

This thesis presents novel findings relating to the position-specific locomotive and performance-related characteristics of elite (club) level rugby union players in England using data gathered via global positioning systems and time-motion analysis over three seasons (2010 – 2013). In terms of sample size, this investigation represents one of the largest conducted and therefore provides information that is more representative than any published thus far. Moreover, the findings reported in the first study (of this thesis) directly challenge the practice adopted previously by researchers in this field of not considering the running capabilities of individual players when calculating their locomotive activities. The consequence of this is that for certain measures (involving speed zones), the values reported herein are a more appropriate reflection of elite players' movement patterns than has been previously reported. For example, it emerged that had previous approaches been used, the average distances covered by players in a match would have been either under- or over-estimated by up to ~ 80% in high intensity running (HIR), and 86% in sprinting. In adopting subsequently the use of speed categories defined in relative terms, position-related differences were observed in locomotion. Namely, as a group, the backs covered the greatest distances, with the scrum half position covering the most (6,542 m) and the tighthead prop the least (4,326 m). The outside backs were found to "sprint" the most, albeit up to ten times less than previously reported. Similarly, position-specific performance behaviours were identified, with the forwards participating in ~ 40% more static exertions than the backs, the second row involved in the most rucks (~ 34% of team total) and the back row the most tackles (12 per match). Among the backs, different demands prevailed; the scrum half executed most passes (over 50% of team total), whereas the inside backs engaged in most tackles (8 per match) and the outside backs carried the ball the most (7 times per match). When broken down into 5-minute periods of play, notable changes in demands were evident. For instance, reductions in total distances (~ 7%), and distances at HIR (~ 16%) occurred in

the second half compared to the first, implying that the onset of fatigue and/or the employment of pacing strategies. Moreover, reductions in HIR following the most intense periods of play were seen (when compared to the average) for the inside (~ 23%) and outside backs (~ 20%), as was the number of static exertions for the front row (~ 21%), back row (~ 24%) and outside backs (~ 45%), suggesting the occurrence of 'transient fatigue' during a match. Collectively the current research provides a comprehensive overview of key physical demands of English Premiership rugby union. Not only does it provide 'typical' position-related data, but also provides some insight into the most intense scenarios for elements of locomotive movement and static exertions, which together could assist practitioners/coaches in devising individualised training programmes to prepare players optimally for competition.

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Chapter 1. Introduction

1.1 A brief overview of rugby union

It is anticipated that 3,000,000 people regularly participate in rugby union throughout the world (www.irb.com). Rugby union is a field-based sport, typically played on a grass pitch measuring approximately 100 m x 70 m with its laws and regulations enforced by the International Rugby Board (IRB).

A competitive match involving adults is 80 minutes in duration and consists of two 40 minute halves (plus stoppage time), with a maximum of a 10-minute break between the two. Each team is made up of 23 players, with the starting line-up comprising 15 players (Figure 1.1). Often positions are sub-categorised and are referred to as the 'forwards' (numbers 1 - 8) and 'backs' (numbers 9 - 15) and are further subdivided into the front row (1 - 3), second row (4 - 5), back row (6 - 8), half backs (9 - 10), inside backs (10, 12 - 13), and outside backs (11, 14 - 15). Both teams are able to make replacements (a player is replaced due to injury) or a substitution (a player is substituted for tactical reasons) at any time throughout the game. Whilst replacement players are allowed to return to the pitch following a blood-related injury or to replace an injured front row player, a player substituted for a tactical reason may not return to the field of play.

As with all team sports the main objective is to win the game through scoring a greater number of points than the opposition. Points can be attained by scoring a try (the ball is put to ground after passing the opponent's goal line; 5 points awarded) kicking a conversion goal (further opportunity to score 2 points by kicking the ball between two goal posts), scoring a penalty try (awarded when foul play has prohibited a true try scoring opportunity, 5 points), scoring a penalty goal (opportunity to kick the ball between the goal posts following foul play, 3 points awarded) and kicking a drop-goal (the ball is kicked from between the two goal posts from general play, 3 points awarded).

Figure 1.1 Starting positions of the 15 players in a rugby union team

1.2 Current available literature and its limitations

Subsequent to its professionalism in 1995, the demands of the game have been reported to have altered, primarily in it becoming a faster paced, ruck dominated game (Eaves & Hughes, 2003). Accompanying this, there has been an augmented interest from spectators and superior financial rewards within the game. With an increase in game demands the expectations of coaches and team staff (e.g. strength and conditioners, sports scientists and clinical practitioners) have increased in terms of gaining a better understanding of match performance and training procedures. Fundamentally, coaches and practitioners endeavour to gain an extensive understanding of the match demands in order to prepare their players optimally, with the ultimate aim to win. Accordingly, there has been a concomitant growth in research activity, particularly in the quantification of movement patterns and the identification of what are considered the 'key' indicators of performance.

The recognition of the key variables or measurements of performance is considered to be important in guiding overall training principles and structures, and essentially helping to prepare players optimally for competition. Collectively, the measures identified are said to address the physical 'demands' of the game and enable the differing roles of playing positions to be distinguished. The process of data collection has primarily been conducted by means of time-motion analysis (TMA) and notational analysis. TMA has been traditionally used to analyse locomotive movement patterns, focussing on absolute and relative total distances travelled (Deutsch, Kearney & Rehrer, 2007; Deutsch, Maw, Jenkins & Reaburn, 1998; Duthie, Pyne & Hooper, 2005; Lacome, Piscione, Hager & Bourdin, 2014; Mclean, 1992; Roberts Trewartha, Higgitt, El-Abd & Stokes, 2008) and distances travelled at various movement speeds (ranging from walking to sprinting). Notational analysis has assessed key performance indicators (KPIs) encompassing the performance-related aspects of the game (e.g. ball carries, tackling, passing, kicking, set pieces, rucking and mauling) (Hughes, Hughes, Williams, James, Vuckovic & Locke, 2012; James, Mellalieu & Jones, 2005; Jones, Mellalieu & James, 2004; Jones, James & Mellalieu, 2008). However, in the last decade, advancements in technology have seen the introduction of micro-technologies (global positioning systems), enabling simultaneous data collection of numerous players, with instantaneous feedback, and removing the extensive time consuming constraints of TMA techniques post-match (Roberts, Trewartha & Stokes, 2006). Global positioning systems (GPS) have now become commonplace in elite rugby union. When comparisons have been made between the two methods of analysis (TMA and GPS), researchers have identified substantial differences in the data collected (Randers, Mujika, Hewitt, Santisteban, Bischoff, Solano, Zubillaga, Peltola, Krustrup, Mohr, 2010), indicating that caution should be taken when comparing the two. Yet since it is anticipated that GPS will be the primary method employed for monitoring both competition and training for the foreseeable future, intuitively it would seem necessary to have an understanding of the objective movement demands of competitive match play utilising GPS technology, particularly to inform training.

Through analysis of both TMA and GPS, research suggests that rugby union players typically spend long durations in low intensity activity interspersed with bouts of high intensity efforts throughout match play (Austin, Gabbett & Jenkins, 2011b; Deutsch et al., 2007; Roberts et al., 2008). More specifically, the forwards are predominantly involved in greater contact efforts and static exertions (which are thought to be a highly demanding and important aspect of match play) than the backs (Lacome et al., 2014; Quarrie, Hopkins, Anthony & Gill, 2013; Roberts et al., 2008). However, there are a number of limitations in the literature thus far that has inhibited a comprehensive analysis of the elite game, particularly at the domestic standard and indeed in the English Premiership. Much of the past video based TMA research on the demands of the professional game are based upon small sample sizes (n < 35), incorporates a limited number of games, and from only a few teams (often just one) (Austin et al., 2011b; Deutsch et al., 2007; Eaton & George, 2006; Roberts et al., 2008). Moreover, studies investigating KPIs have similarly utilised small samples of players (James et al., 2005; Jones et al., 2004) or have examined publically available data from national and international governing bodies (Ortega, Villarejo & Palao 2009; van Rooyen, Lambert & Noakes, 2006; Vaz, Mouchet, Carreras & Morente, 2011) with particular reference to the fundamentals of success (Hughes & White, 1997; Hunter & O'Donoghue, 2001; Jones et al., 2004; Ortega et al., 2009; Prim, van Rooyen & Lambert, 2006; Vaz, Rooyen & Sampaio, 2010) based characteristically (with few exceptions) on team performances rather than on individual positional demands. As a consequence, investigations have grouped playing positions primarily into forwards and backs, or into sub-classifications, as previously discussed. Rarely have researcher's individualised positional groups, with most omitting the seemingly pivotal scrum half position (Deutsch et al., 1998; Deutsch et al., 2007; Duthie et al., 2005; Roberts et al., 2008). What is more, scarcely has the movement patterns and KPIs from the same data source been analysed, hence limiting the availability of extensive information of the demands of competitive play. This said, whilst the recent work of Quarrie et al. (2013), the most extensive to date (involving 763 players), provided a comprehensive insight into competition demands per individual position, their findings only alluded to the international standard demands and their superiority when compared to the professional club standard. However, at the professional club level, again owing to the restrictions of sample size, little data exists on the physical demands per playing position (Eaton & George, 2006; James et al., 2005; Jones, West, Crewther, Cook & Kilduff, 2015). Indeed, with typical player sample sizes being less than five in each playing position, one could question whether the findings are representative of the game *per se* or more characteristic of the individual(s) analysed. Certainly, researchers have recommended that data is required to have stabilised in order for a true representation of the findings to be identified, hence a normative profile (Hughes, Wells & Evans, 2001; Eaves, Hughes & Lamb 2003), although few have included or even acknowledged these fundamental recommendations. Therefore, the findings of some investigations may not truly be representative of the game.

Moreover, following the rapid developments of GPS technology its use within team sports and certainly within elite rugby union has grown exponentially. Indeed, for the purposes of the investigations described in this thesis, the IRB implemented an experimental law variation to rule 4.1 (2010-2013) to allow the use of such devices in competitive English Premiership matches. However, to-date, there are only a handful of studies on elite rugby union that have utilised GPS technology in an attempt to augment our understanding of competitive match play. Yet, similar to TMA investigations, with the exception of Jones et al. (2015) who investigated 33 players over 13 matches in the Celtic and European Cup matches, the findings are more representative of individual case studies, with sample sizes ranging between 2-8 players and from one to three matches (Coughlan, Green, Pook, Toolan, O'Connor, 2011; Cunniffe, Proctor, Baker & Davies, 2009; Reid, Cowman, Green & Coughlan, 2013; Suarez-Arrones, Portilloc, González-Ravé, Muńoz & Sanchez, 2012). To the author's knowledge, no information on the physical demands of match play in the English Premiership have been reported when GPS has been the method of choice. Indeed, the only two studies that have investigated the demands (through TMA) within the English Premiership have been based on data from just one team (Eaton & George, 2006; Roberts et al., 2008) with relatively small number of matches analysed. Currently scant research has endeavoured to identify match demands when competing in the English Premiership, particularly when analysing both locomotive and performance-related demands. Moreover, of the data available based on the English Premiership, it is mostly representative of the early twenty-first century and considering the work of Austin et al. (2011b) whereby increased demands were apparent in the 2008-2009 season compared to 2000-2001, it is therefore plausible that a more contemporary analysis of English Premiership match demands are warranted. It would hence seem conceivable that in order to quantify objectively the physical demands of the contemporary game, utilising the prevalent technology (GPS), further investigations are required at the elite professional club level, with particular focus on the analysis of all individual positions, on a more representative data set within the English Premiership. Additionally, whilst predominantly researchers have focused on the general match demands over entire games, the evidence from other team sports (soccer, rugby league, Australian rules football) has demonstrated that movement and performance-related patterns vary throughout the duration of the game, proposing evidence of fatigue, pacing and peak efforts (Aughey, 2010; Bradley & Noakes, 2013; Mohr, Krustrup & Bangsbo, 2003; Waldron, Highton, Daniels & Twist, 2013). Currently, very little information exists on such fluctuations in rugby union, which potentially could provide practitioners with invaluable data on situations interpreted as the most intense periods and augment our understanding of the game and aid in optimal player preparation.

Therefore, by accessing one of the largest data sets of its kind, the primary aim of the current programme of research was to determine the physical demands of the English elite rugby union game through the use of GPS. The research set out to assess key performance variables associated with the locomotive and performance elements of match play, and to describe and compare activity profiles of individual positions and positional groups, and subsequently report on the movement and performance changes throughout match play. It is hoped that such knowledge might have direct implications for the development of optimal training regimes and recovery strategies following competition.

1.3 Aims and Objectives

1.3.1 Aim

The main aim of this investigation is to provide an analysis over three competitive seasons of the demands of individual positions in elite English rugby union in order to gain an in-depth understanding of the associated movement demands (both locomotive and game play actions).

1.3.2 Objectives

1. To establish an appropriate classification of locomotive speed in rugby union performance analysis. This will be achieved by examining the appropriateness of using relative speeds (percentages of individual peak speeds attained during match play), to identify individualised thresholds for subsequent analyses of locomotive movement in elite rugby union.
2. To quantify the movement characteristics of elite rugby union players during competitive match play and identify whether significant position-related differences exist.
3. Utilise video analysis of English Premiership rugby union matches to quantify the position-specific performance-related demands over three seasons of competition.
4. Identify changes (every 5 minutes) in high intensity running (HIR) and static exertions across elite rugby union match play in different positional groups, and thus determine whether such changes reflect general fatigue, 'transient' fatigue, and /or the adoption of pacing strategies.

Chapter 2. Review of Literature

2.1 Introduction

The intention of this chapter is to review the literature that has assessed the physical demands and indicators of performance of elite level rugby union through the use of time-motion, notational and global positioning systems (GPS) analysis. In addition, it will present an appraisal of the acceptability of GPS technology to provide accurate information on team sports, particularly rugby union. The section will also explore research that has investigated movement changes that occur throughout match play and the extent to which these are reflective of fatigue occurrence. Finally, the chapter will seek to synthesise what is currently understood on this theme and thereby identify the scope for future research.

2.2 Rugby Union

Rugby union is a multifaceted team sport, which requires a broad range of physical attributes depending on an individual's playing position and associated specific match demands (Duthie, Payne & Hooper, 2003). However, due to its complexity (including factors such as multiple players performing at the same time and intermittent and stochastic movement patterns of varying intensity and duration) and the number of factors that can potentially influence a match's outcome, quantifying the physical demands of rugby union has been problematic. Nonetheless, numerous attempts have been, and continue to be made (Coughlan et al., 2011; Cunniffe et al., 2009; Deutsch et al., 1998; Deutsch et al., 2007; Duthie et al., 2005; McLean, 1992; Roberts et al., 2008; Venter, Opperman & Opperman, 2011). Importantly, following rugby's change to a professional sport in August 1995, applied sports scientists and coaches have recognised the need for an improved understanding of the game in order to enable them to prepare elite players optimally to withstand the stresses and strains of the 'new' game (McMillan, 2006). For example, different demands between the amateur and professional games are now evident, with a greater emphasis on fast, dynamic play

(Eaves & Hughes, 2003), a need for improved levels of fitness inclusive of aerobic and anaerobic capacity, strength and speed (Duthie et al., 2003) and an accompanying increase in injury rate since the transition to a professional sport (Garraway, Lee, Hutton, Russell & Macleod, 2000).

2.3 The Assessment of the Physical Demands of Rugby Union

2.3.1. Performance Analysis

Performance analysis is the investigation of sports performance and is used to provide both coaches and athletes with important information on match performances (Franks & McGarry, 1996). Performance analysis is often used to assess the demands of rugby union and other team sports. Techniques such as video-based notation and time-motion analysis (TMA) have primarily been used to quantify the technical, tactical and physical demands (Deutsch et al., 1998; Deutsch, et al., 2007; Docherty, Wenger & Neary, 1988, Duthie, et al., 2005; Eaton & George 2006; Lacome et al., 2014; McLean, 1992, Quarrie et al., 2013; Roberts et al., 2008). However, in more recent times, through the development of technology, the use of global positioning systems (GPS) has emerged as an alternative method (Austin, Gabbett & Jenkins 2011a; Austin et al., 2011b; Austin & Kelly, 2013; Coughlan et al., 2011; Cunniffe et al., 2009; Coutts, Wuinn, Hocking, Castagna Rampinini, 2010; Gabbett, Jenkins & Abernethy, 2010; Gabbett, Jenkins & Abernethy, 2012; Gabbett, 2012; Gabbett, 2013a; Gabbett, 2013b; Hartwig, Naughton, & Searl, 2011; Jones et al., 2015; McLaren, Weston, Smith, Cramb & Portas, 2015; McLellan, Lovell & Gass, 2011b; Waldron, Twist, Highton, Worsfold & Daniels, 2011b; Waldron et al., 2013; Wisbey, Montgomery, Pyne & Rattray 2010). Notational analysis, TMA and GPS can provide useful information of the physical demands required of an athlete both during competition and training (Taylor, 2003) via quantifying movement patterns (Dobson & Keogh, 2007). Such an approach is also helpful in objectively identifying the occurrence of fatigue during competition (Mohr et al., 2003; Bradley & Noakes, 2013), determining differences between playing standards (Gabbett, 2013b), optimising training to imitate specific match demands, predicting the physiological consequences of a game and identifying prime recovery periods in the days after a match (Johnston, Gabbett, Jenkins, Hulin, 2014).

2.3.2 Notational and Time Motion Analysis

2.3.2.1 A Brief History

Notational analysis is a technique frequently used in field game sports to objectively analyse and report on dynamic and complex match situations, providing information on five key areas including the technical and tactical evaluation of the game, and player and coach education and performance modelling (O'Donoghue, 2010). Akin to notational analysis, TMA is primarily denoted by the use of video footage to capture events that occur during a designated time frame and has been the principal analysis technique in determining the physical demands (i.e. locomotive movement demands) in team sports over the past thirty years (Carling, Bloomfield, Nelsen & Reilly, 2008). It uses a range of manually operated cameras with both singular and multiple views and semi-automated multiple views systems (e.g. Amisco Pro, DatatraX, TRACAB, Pro Zone, Trak Performance, Venisco, VenaTrack) to track players during activity (Aggarwal & Cai, 1997).

It has been suggested that the earliest forms of notation systems were devised by Henry Chadwick and Hugh Fullerton as early as the mid 1850's and 1894 respectively (Eaves, 2013, as cited in Eaves & Worsfold, 2014). However, the first publication in sports notation is believed to have been by Hugh Fullerton, in May 1910, when analysing the game of baseball (Eaves & Worsfold, 2014; Hughes & Franks, 2004). Yet, it wasn't until the work of Messersmith and colleagues emerged in the 1930's that the first notation systems, specifically devised for sport, are thought to have been designed. Utilising such methods, Messersmith and associates provided detailed information on the distances travelled by basketball players during match play (Messersmith & Corey, 1931; Messersmith & Bucher, 1939; Messersmith, Laurence & Randels, 1940; Messersmith, 1944). The first evidence of rugby analysis however, was in 1907 when Maurice Martin and Fernand Bidault detailed information on the key game actions, including location on the pitch and their duration (Humbert, 2010, cited in Eaves & Worsfold, 2014). Yet, until recently few researchers have continued to provide such extensive and comprehensive analysis of team sports, and indeed, rugby union. Due to the accessibility of computers in the late 1970's, the development of specific notational analysis templates surged and thus increased the digital investigations into the tactical, technical and movement patterns in team sports (Hughes & Franks, 2004). Hughes and Franks (2004) reported researchers often reference and make comparisons to the work of Reilly and Thomas (1976) for the systematic methods employed for analysis, albeit succeeding the original work of Fullerton and Messersmith and colleagues. Reilly and Thomas (1976) conducted an investigation into the work rate profiles of English First Division soccer players during 51 competitive matches through combining hand notation, video footage and the scaling of a soccer pitch. Total distances were investigated, as were different locomotive types, including standing, walking, backwards movements and running. Based on locomotive observations, similar to the earlier work, Reilly and Thomas (1976) suggested that additional categories of running intensities (jogging, cruising and sprinting) should be analysed, and displayed as frequencies and durations (determined by counting and using a stop-watch) through cues on the playing pitch. Such procedures set a precedence for analysing team sports and researchers have used and adapted this work to form the basis of their own investigations (Bloomfield, Polman & O'Donoghue, 2004; Boddington, Lambert, St Clair Gibson & Noakes, 2002; Deutsch et al., 1998; Deutsch et al., 2007; Duthie et al., 2005; Mohr et al., 2003; Ohashi, Togari, Isokawa & Suzuki, 1988; Quarrie et al., 2013; Roberts et al., 2008; Sykes, Twist, Hall, Nicholas & Lamb, 2009). Significantly, Reilly and Thomas (1976) noted the importance of the reliability and validity of their system (reliability coefficients ranged from 0.91 to 0.97), which few researchers had previously included and remarkably to-date, are still relatively scarce within notational analysis and TMA studies.

2.3.2.2 Reliability Analysis

Often researchers design new specific analysis systems to carry out performance analysis investigations in sports. Inherently data variability can affect the ability to determine a real difference between performances (Atkinson & Nevill, 1998; O'Donoghue, 2007). In using computer-based analysis systems additional errors can occur due to operational errors or hardware or software errors (Hughes & Franks, 2004). Therefore it is imperative that acceptable repeatability and accuracy of the system is demonstrated prior to its use (Hughes & Franks, 2004).

However, in the past a large number of performance analysis studies, including rugby union investigations, have neglected to notate any information on the reliability of the systems employed. In fact, Hughes, Cooper and Nevill (2002) reported that as much as 70% (from a total of 67 papers presented at the early conferences of Science and Football, Science and Racket Sports and Science and Notational Analysis of Sport) did not discuss any reliability analysis. It was further determined that of the 30% of papers that did, 15% of these studies applied inappropriate statistical tests, namely through the use of correlation coefficient statistics to identify reliability. Such statistics have previously been demonstrated that on their own are insufficient in confirming reliability (Bland & Altman, 1986; O'Donoghue, 2007). Whilst Bland and Altman (1986) suggested the use of 95% Limits of Agreement (LoA) could provide an alternative method, its use in notational analysis investigations is restricted as it assumes the within-subject differences are normally distributed (Nevill, Atkinson, Hughes & Cooper, 2002), which is often not the case. Hughes et al. (2002)

proposed a more appropriate indicator of reliability would be to use a percentage error equation, adapted from Bland and Altman (1986) plots, to provide a visual representation of the level of agreement. The authors stressed however, that a number of stipulations should be applied to reduce errors in the reliability. For example, it was suggested that all data should be in its raw form (remarking that processed data could mask observational errors), retain its sequence to allow cross-reference comparisons and to ensure a similar level of analysis is carried out as the intended statistical analysis (Hughes et al., 2002). Although, whilst the inclusion of reliability information within performance analysis investigations has increased substantially since the work of Hughes and colleagues (2002) and within rugby union investigations (Austin et al., 2011a; Austin et al., 2011b; Duthie et al., 2006; Deutsch et al., 2007; Roberts et al., 2008; Vaz et al., 2011), limitations still exist. In the main, details often remain inadequate, with reliability frequently reported as a summary of the data combined as opposed to individual variables or individual players (Hughes, Cooper & Nevill, 2004). However, as some variables occur more frequently than others, it could be that a large number of matches need to be analysed in order to gain an adequate sample size for certain variables, thus making it difficult for researchers to present individual variables or player reliability statistics (Cooper, Hughes & O'Donoghue, 2007). In addition O'Donoghue (2007) recently cast further doubt on the use of percentage errors to provide an adequate measure of reliability, adding conflict to which techniques are most appropriate to use.

Consequently, Cooper et al. (2007) proposed statistical methods designed to assess reliability in performance analysis investigations should identify any systematic bias or degree of random variation between test and retest data. They proposed it should be an index of absolute agreement that makes no assumptions regarding the data being normally distributed, be free from dependency on high within-systems variance and importantly, be able to resolve reliability issues of sport performance indicators when assessed as individual variables. Subsequently, Cooper et al. (2007) amalgamated the work of Bland and Altman (1999) and

Nevill et al. (2002) on how to treat non-parametric data to provide a simplistic method to assess the reliability of data entered into sports performance analysis systems. It proposed the reliability of data could be determined by 'calculating a simple test retest difference within a reference value thought to be of no practical importance' (Cooper et al., 2007, p. 106). It was suggested match play should be segmented into two-minute timed cells and the occurrence of the selected performance indicators recorded sequentially within that time period and repeated thereafter for each subsequent time period to assess agreement. Although, simplistic in nature, this method was deemed useful to performance analysts. However to-date, excluding the exemplar referred to in the original investigation, few researchers have employed this technique within a field setting (Thomson, Lamb & Nicholas, 2013), therefore questioning its current application in a practical environment.

The use of Cohen's Kappa coefficient (1960) and Weighted Cohen's Kappa coefficient (1968) have been suggested as useful methods within notational analysis (Robinson & O'Donoghue, 2007) as it demonstrates the ability to achieve construct validity (O'Donoghue, 2007). To this end it has frequently been the chosen technique in a number of investigations (Bloomfield et al., 2004; McLaughlin & O'Donoghue, 2001; Tenga, Kanstad, Ronglan & Bahr, 2009). The use of Cohen's Kappa coefficient (1960) statistic is believed to be particularly robust as it accounts for the proportion of incidences that agreement occurs due to chance. However, as a statistic it is very severe which treats every disagreement alike (Cohen, 1968), meaning anything other than an exact agreement is classified as a total disagreement (Bloomfield et al., 2004; Robinson & O'Donoghue, 2007). Yet often in performance analysis investigations, particularly when dealing with ordinal data, the differences in agreement can vary, ranging between large and small differences (Cohen, 1968; Bloomfield et al., 2004; Robinson & O'Donoghue, 2007). In such instances the use of the Weighted Kappa coefficient could be more appropriate as it acknowledges the differential weighted agreements and makes allowances for this (Cohen, 1968). Nonetheless, whilst it may not be the most suitable technique for all performances (O'Donoghue, 2007), as it has been found to achieve construct validity, it is believed to be an appropriate and alternative technique for reliability (O'Donoghue, 2007). On this basis, it has been employed as a viable method to test inter- and intra- reliability of performance analysis systems (Bloomfield et al., 2004; Tenga et al., 2009).

2.3.3 Reliability and Validity of TMA within Rugby Union

Reliability reflects the degree of consistency of a measure, whilst validity is the degree to which it actually measures what it states it measures (Atkinson & Nevill, 1998). Both of these concepts are essential to performance analysis, particularly when small changes (or differences) can have meaningful effects. However, the reliability and validity of TMA techniques across all team sports, have been shown to be variable owing predominantly to the methodologies employed, the lack of standardised procedures for researchers to follow (Carling et al., 2008) and the subjective nature of selecting the movement classification categories (Duthie et al., 2003).

Nonetheless, rugby union researchers, in general, have reported relatively reliable and valid findings when using manually operated cameras in TMA and notational analysis investigations (Deutsch et al., 1998; Docherty et al., 1988; Duthie et al., 2003; Eaves & Hughes, 2003; Eaves, Hughes & Lamb, 2005; James et al., 2005; Jones et al., 2004; Jones et al., 2008; Lim, Lay, Dawson, Wallman & Aanderson, 2009; Lim, Lay, Dawson, Wallman & Aanderson, 2011; McLean, 1992; Roberts et al., 2008), albeit typically dependent upon the movement classifications and the performance indicators selected. Deutsch et al. (1998) simulated a game scenario for a 20-minute playing period using markings of known distances to compare the validity of mean and total distances via TMA. The results demonstrated high levels of validity on the basis of high correlation coefficients ranging between 0.738 – 0.939 for utility (backwards and lateral) movements and jogging movements, respectively. Similar findings were reported for total duration in the different movement categories, with the coefficient of variation (CV) ranging between 1.74 – 4.94% and 1.88 - 4.86% for mean duration of movements at different speeds. In a study using similar methods, Deutsch et al. (2007) reported the percentage technical error of measurement (TEM) to range between 1.6 – 4.8% for intra-coder reliability for total time, occurrences, relative time and mean duration and 4.7 – 8.7% for inter-coder reliability when three operators were employed. Duthie et al. (2003) however, reported that intra-tester reliability was only moderate to poor (CV = 5.8 - 11.1%) for the methods used to determine total time and mean duration of each movement. TEM was found to vary for the frequency of individual movements ranging between good-to-poor (4.3 - 13.6%). Roberts et al. (2008) suggested that a reliable technique had been established for assessing work profiles of field sports players, reporting intra-operator and inter-operator reliability (CV) of 0.5% and 0.9%, respectively. Additionally they found calculated speed to be within 8.3% of the actual speed determined by photocell equipment, and estimated distances within 2.1% of the actual values. However, whilst the inclusion of reliability analyses is more prevalent within recent TMA studies, there is still a need for more comprehensive analysis. Across the investigations, the reliability results lack specificity and do not match the depth of the statistical analysis performed. For example, although some authors have stated the reliability of individual variables was assessed, the findings were presented as a range, reflecting the reliability and accuracy of combined movements rather than to individual movements (Deutsch et al., 1998; Deutsch et al., 2007; Duthie et al., 2003), an approach deemed essential by Hughes and colleagues (2002). Furthermore, the use of correlation coefficients to represent the reliability and accuracy of a system is somewhat contentious. Bland and Altman (1986) disputed the use of correlation coefficients for reliability, asserting that whilst the change in a scale would not affect the correlation, undoubtedly it would affect the agreement. Nonetheless, in the main the reliability and validity of TMA systems in sports have been demonstrated, albeit their interpretations are very dependent on individual methods employed.

Semi-automatic tracking systems utilise visual image recognition software to determine unique factors of an individual, which could be a particular colour, size or shape (Carling et al., 2008). The reported accuracy of semi-automatic systems in rugby union investigations is relatively limited, often with authors relying heavily on manufacturers' statements of accuracy (Dobson & Keogh, 2007) or reports from other codes of sports. Eaton and George (2006) used the semi-automatic system Prozone to determine movement patterns of elite rugby union players. It was reported that on installation of the sensors, calibration took place in reference to an object at ground level, which was moving at a known speed and distance. However, no statistical evidence was provided of either the reliability or validity measurements, albeit the authors remarked they could not obtain this information from the manufacturers of the equipment used. Subsequent studies addressing its reliability and validity in soccer have emerged (Di Salvo, Collins, McNeill & Cardinale, 2006), with researchers reporting the intra- and inter-observer reliability to be high for both total distance and movement intensities when five randomly selected players were analysed on two separate occasions by two trained analysts. Intra-observer reliability (CV) was shown to be 1.0% and < 1.2% for total distance and total distance across varying velocities, respectively. However, an increase in running velocity produced a decrease in reliability (CV = 2.4%) which, was augmented when sprinting (CV = 3.5%) (Bradley, O'Donoghue, Wooster & Tordoff, 2007). Moreover, high validity was demonstrated when runs of known distances were measured over straight, curved and turning runs (90°) at differing velocities. Yet, the two codes of rugby have some fundamental differences, principally the contact element. Therefore, whilst soccer studies (Bradley et al., 2007; Di Salvo et al., 2006) have provided evidence of the reliability of the Prozone system for identifying locomotive movements, there is still a scarcity of information on its reliability and validity in determining contact and static elements in the game. Recently, investigations using alternative semi-automatic tracking systems (Amisco Pro & Verusco Technologies) to determine movement demands in rugby union have emerged (Lacome et al., 2014; Quarrie et al, 2013). Lacome et al. (2014) reported the Amisco Pro systems demonstrated a high reliability in identifying locomotive movement patterns, based on earlier findings from Zubillaga, Gorospe, Mendo and Blanco-Villaseñor (2007). However, no statistical details were provided. Additionally, Quarrie et al. (2013) used a semi-automatic system, Verusco Technologies Inc., to investigate the movement demands of elite rugby union players. The validity of the system to identify the location of a player and determine distance travelled around the pitch was found to be acceptable, with an error of ±140 mm when compared to distances measured via a tape measure. For the analysis of performance-related elements of match play both Lacome et al. (2014) and Quarrie et al. (2013) used notational analysis systems, though neither provided any statistical evidence of the accuracy of the methods used for this aspect of their investigations. Similarly, whilst Hughes et al. (2012) noted that all data were tested for accuracy and reliability, they failed to report any further information on it. However, this is not typical of the research area in which the reported reliability and validity of notational analysis systems within rugby union investigations has increased enormously following the work of Hughes and Bartlett (2002). For example, James et al. (2005) successfully created a valid and reliable method for the analysis of individual elite rugby union players. The percentage errors were found to be low for all the analysed variables, noting a mean and standard deviation of 1.97 ± 3.14% for intra-reliability, although substantially higher for inter-reliability, with a mean and standard deviation of 11.09 ± 8.61%. However, as the analysis was conducted solely by the main analyst, the statistics were deemed acceptable. Similarly, Jones et al. (2004) determined the intra- and inter-reliability of the notational analysis system to be < 5% and therefore acceptable to use when examining the predictors of success among winning and losing teams. Yet, both investigations reported the reliability of combined variables, which has previously been suggested to increase the errors in reliability (Hughes et al., 2001) and potentially mask reliability errors of individual variables. In fact, despite the recommendations from Hughes and Bartlett (2002) for reliability to be presented in reference to individual variables opposed to all combined together, few authors have adopted such a style, with the exception of Eaves and Hughes (2003) and Eaves, Hughes and Lamb (2005). Eaves and Hughes (2003) reported individual intra-observer reliability statistics for two observations for ruck times (93% for first versus second observation and 96% for second versus third observation) and activity times (96% for first versus second observation and 97% for second versus third observation) when investigating the differences in patterns of play between the amateur and professional eras. Moreover, in a later study investigating the effect of professional status and the occurrences of game actions, Eaves, Hughes and Lamb (2005) identified the intra-observer reliability level for each of the 13 game actions analysed was 100%, excluding ruck/maul agreement which was 98.5% and total pass frequency 88.9%. By individualising the game actions it highlighted the reduced reliability of total pass frequencies, which allowed the authors to amend the procedures used to ensure reliability was improved.

Evidently, the TMA and notational analysis techniques used within rugby union in the main have demonstrated to be moderately to highly reliable and valid, albeit specific to the individual designs in each investigation. Whilst some of the statistics used (correlation coefficient) have previously been recognised as being inappropriate for quantifying the reliability and accuracy of a method (Bland & Altman, 1986; O'Donoghue, 2007), the findings overall have supported the use of TMA and notational analysis techniques to accurately determine physical demands of rugby union match play. However, limitations of such techniques remain, primarily in the lengthy process time required to analyse match play via TMA (Bloomfield, Polman & O'Donoghue, 2007), the confinements of space and positioning of cameras and principally the identification or selection of movement classifications.

2.4 Selection of Movement Classifications for TMA

When analysing work profiles of team sport players through video based TMA, researchers have previously selected certain locomotive actions to characterise movement patterns and identify work performed by athletes. Whilst the first publication on movement analysis is believed to be by Fullerton (1910), authors often erroneously reference the "original work" of Reilly and Thomas (1976) when outlining movement classifications. In accordance with the earlier work of Fullerton (1910), Reilly and Thomas (1976) categorised movement patterns into different speed classifications. Accordingly, a trained observer attended the pitch side with an audio player and a hand notation analysis system, noting the duration of match actions for players (Reilly & Thomas, 1976). Players were instructed to move at different speed intensities (including 'standing', 'walking', 'backwards movements', and running actions termed 'jogging', 'cruising' and 'sprinting') and select self-regulating stride patterns in a non-competitive environment. Subsequently, utilising the estimated stride patterns, speed and the duration spent in each zone during match play, distances travelled were quantified. However, the investigation was not without criticism, particularly regarding the subjective manner of the identification of movement classifications and the assumptions that player stride patterns stayed constant throughout different speed zones in both non-competitive and competitive match play. Moreover, Reilly and Thomas (1976) further neglected to include any specific or detailed information of the selected movement classification definitions. Nevertheless, to-date this model of methods is still frequently copied and referred to, albeit inhibited by the rather 'dated' data-capture processes and limitations.

Whilst locomotive speed classifications were labelled based on subjective observations in Reilly and Thomas (1976), utilising their methodological framework, other 'key' studies introduced the use of predetermined speeds to classify locomotive movement (Bangsbo, Nørregard & Thorsøe, 1991). The work of Bangsbo and colleagues (1991) was one of the earliest publications to identify predetermined speed classifications (Table 2.1). Players were instructed to move at different locomotive intensities in a non-competitive environment to record their movement patterns. These were coupled with video captured from competitive soccer matches to help identify speed categories. In accordance with Reilly and Thomas (1976), Bangsbo et al. (1991) further proposed locomotive movements should be analysed as high and low intensity efforts as a good reflector of the physiological demands placed on the body is believed to be the amount of high intensity efforts undertaken during match play. Yet again, the speed classifications were determined rather subjectively and similar to Reilly and Thomas (1976) with little consideration for the differences in locomotive movement patterns of non-competitive and competitive environments. However, whilst the work of Reilly and Thomas (1976) and Bangsbo et al. (1991) has been frequently referenced when determining speed classifications, over the last decade notable modifications have appeared in the literature, often with little justification as to why. For example, Rampinini, Bishop, Marcora, Ferrari, Sassi & Impellizzeri (2007a) (a frequently cited investigation), although investigating soccer demands in the same manner as Bangsbo et al. (1991), selected alternative speed categories (see Table 2.2) to those of Bangsbo et al. (1991), with little explanation as to how or why the new speed categories were determined and utilised. To this end, inconsistency across all sports has been produced, thus causing great difficulty when comparing studies. (See Tables 2.1-2.7 for TMA studies).

Indeed, the methods employed to analyse and identify locomotive movement patterns within TMA investigations vary predominantly between subjective descriptive methods (Austin et al., 2011b; Deutsch et al., 2007; Docherty et al., 1988; Duthie et al., 2005; McLean, 1992) (Tables 2.3 – 2.5), and predetermined speed categories (Eaton & George, 2006; Quarrie et al., 2013; Roberts et al., 2008) (Tables 2.6 – 2.7). However, a particular contentious issue in the current literature is the arbitrarily determined absolute speed classification zones for all individual players, irrespective of playing position, physique or physiological capabilities.

The use of absolute speed classifications does not take into account the obvious variability in running capabilities between individual athletes and the associated internal and external load that accompanies it (Viru & Viru, 2001). What is more, whilst the use of absolute speed zones *per se* causes controversy among authors, this is augmented by the lack of consistency in the labelling of speed categories across the TMA literature. For example, whilst Rampinini et al. (2007a) proposed that moving at a speed greater than 25.2 km·h^{-1} constituted a 'sprint', Bangsbo et al. (1991) suggested that only when an athlete was moving at 30 km·h^{-1} was an athlete deemed to be sprinting. Besides these discrepancies, numerous authors have presented an overlap in the selected speed classifications (Quarrie et al., 2013; Rampinini et al., 2007a; Roberts et al., 2008). For instance, Rampinini et al. (2007a) outlined walking speed to be between 0.7-7.2 km·h^{-1} and jogging between 7.2-14.4 km·h^{-1}, therefore casting doubt on what an athlete was actually doing at a speed of 7.2 km·h^{-1} (walking or jogging?). Consequently a consideration of the speed classifications should be noted when interpreting the data.

Table 2.1 Movement classification outlined by Bangsbo et al. (1991).

Movement	Speed (km·h^{-1})	Intensity
Standing	0	Standing
Walking	6	Walking
Jogging	8	Low Intensity Running
Low Speed Running	12	Low Intensity Running
Moderate Speed Running	15	High Intensity Running
High Speed Running	18	High Intensity Running
Sprinting	30	High Intensity Running
Backwards running	12	Low Intensity Running
Other (Heading & Tackles)		

Table 2.2 Movement classification outlined by Rampinini et al. (2007a).

Movement	Speed ($km \cdot h^{-1}$)	Intensity
Standing	0 – 0.7	Standing
Walking	0.7 - 7.2	Walking
Jogging	7.2 – 14.4	Low Intensity Running
Running	14.4 – 19.8	High Intensity Running
High Speed Running	19.8 – 25.2	Very High Intensity Running
Sprinting	>25.2	Very High Intensity Running

Table 2.3 Pre-professional rugby union movement descriptors (after Reilly & Thomas, 1976; Docherty et al., 1988; McLean, 1992).

Movement	Description
Standing	No locomotive movement
Walking	Forwards, sideward' and backwards strolling locomotive movement
Jogging	Slow running in which no effort was made to stride or accelerate
Running	Running with an elongated stride but without full effort
Sprinting	Running at maximum speed or full effort
Non-Running Intense Activity	Includes tackling, pushing in scrum, ruck or maul, and actively competing for the ball

Table 2.4 Professional era rugby union movement descriptors.

	Duthie et al. (2005)	Deutsch et al. (2007)
Movement	Description	Description
Standing	No locomotive movement	Standing or lying on the ground without being involved in pushing or any other game activities
Walking	Locomotive movement without a flight phase	Walking forwards or backwards slowly with purpose. One foot is in contact with the ground at all times.
Jogging	Locomotion with a flight phase but minimal arm swing	Running forwards slowly to change field position, but with no particular haste or arm drive.
Cruising		Running with manifest purpose and maximal effort (3/4 pace) (Deutsch et al., 1998; Docherty et al. 1988)
Striding	Similar to jogging with more active arm swing	
Sprinting	Maximal locomotive effort	Running with maximal effort. This is discernible from cruising by arm and head movements.
Static Exertion	Scrums, rucks and mauls	
Jumping, lifting, tackling	Total number of made by each player was counted	Jumping in a lineout or to catch a ball in play
Utility		Shuffling sideways or backwards to change field position. Usually a defensive or repositioning movement. This does not include aimlessly walking slowly backwards.
Rucking/Mauling		Attached to an active ruck or maul. Once the ball exits the ruck or maul, or the referee calls the end of the play, the player is no longer considered to be engaged in rucking/mauling, and is deemed to be standing still.
Scrummaging		Attached to an active scrum. As above, once the ball exits or the play is stopped, the scrum is no longer active.

Table 2.5 Professional era rugby union movement descriptors continued.

	Austin et al. (2011b)
Movement	Description
Standing	Standing or laying on the ground without being involved in pushing or any other game activities.
Forward Walking	Walking forwards slowly with purpose. One foot in contact with the ground at all times.
Backward Walking	Walking backwards slowly with purpose. One foot in contact with the ground at all times.
Forward Jogging	Jogging forwards slowly in order to change field position, involves a flight phase, with minimal arm swing, but with no particular haste.
Backward Jogging	Jogging backwards slowly in order to change field position, involves a flight phase, with minimal arm swing, but with no particular haste.
Forward Striding	Running with manifest purpose and effort, accelerating with long strides, yet not at maximal effort (3/4 pace) e.g. running into a back line to receive the ball.
Forward Sprinting	Running with maximal effort. Discernible from striding by maximal arm and stride movements.
Lateral Movement	Shuffling sideways (transverse), in order to change field position. Usually a defensive or repositioning movement.
Tackling	A tackle occurs when the ball carrier is held by one or more opponents and is brought to ground.
Kicking	Any kick in play including; kick-off, kick to touch, chip-kick, punt, and field goal.
Static Holds	The involvement of lifting a player in a lineout movement.

Table 2.6 Predetermined speed classifications of locomotive movement descriptors in rugby union.

	Eaton & George (2006)		Roberts et al. (2008)	
Movement Classification	Speed ($km \cdot h^{-1}$)	Intensity Level	Speed ($km \cdot h^{-1}$)	Intensity Level
Standing	<1.8	Low	0 – 1.8	Low
Walking	>1.8	Low	1.8 – 6.12	Low
Jogging	>7.2	Low	6.12 – 12.96	Low
Runs	> 14.4	High		
Medium Intensity Running			12.96 – 18	Low
High Speed Runs	> 19.8	High		
High Intensity Running			18 – 24	High
Sprinting	> 25.2	High		
Maximal Speed Running			> 24.12	High
Static Exertions				High
Rucking\Mauling	High			
Scrummaging	High			
Tackling (Tackler/Tackled)	High			
Lineout (Jumper\Lifter)	High			

Table 2.7 Predetermined speed classifications of locomotive movement descriptors in rugby union continued (Quarrie et al., 2013).

Movement Classification	Speed ($km \cdot h^{-1}$)*
None	≤ 0.36
None	0.36 -7.2
None	7.2 – 14.4
None	14.4 – 21.6
None	21.6 – 28.8
None	≥ 28.8

*speed converted from $m \cdot s^{-1}$ to $km \cdot h^{-1}$ (as published), these boundaries overlap

2.5 Physical Demands of Rugby Union via TMA

2.5.1 Pre-Professional Era

Docherty et al. (1988) and McLean (1992) produced some of the initial work on the physical demands of rugby union during the pre-professional era. Importantly, they identified that whilst the game lasted 80 minutes, the ball was in play on average for just 29 minutes (36% of total game time) (McLean, 1992), although this was considerably greater than reported by Eaves and Hughes (2003) who suggested the ball was in play for 26.1% of total game time prior to the professional era. This inconsistency however, could be due to the varying methodologies employed. McLean (1992) summated periods of play throughout match play to equate to ball in play time and did not acknowledge the potential of extra time (due to stoppages) and merely used 80 minutes of play time exactly to make the calculations. Furthermore, whilst Eaves and Hughes (2003) determined the start of the scrum was at the presentation of the ball, McLean (1992) included ball in play time from the formation of the scrum, which could add some considerable time on, particularly if a high number of scrum resets occurred within a game. Nonetheless, authors are in agreement that match play was predominantly made up of low intensity activity (as much as 85%), with a smaller percentage competed at a higher intensity activity (15%), 6% of which was attributed to running activity, and 9% to non-running activity (static exertion) (Docherty et al., 1988). Docherty et al. (1988) illustrated that 63% of rest periods exceeded the length of work periods (1:1-1.9), supporting the dominance of low intensity activity throughout a match. Characteristically players in the forward positions, specifically the props, spent 20% more time in intense activity (when both running locomotive and static exertions were considered) than the backs, although the centre positions were typically involved in a greater percentage of higher intensity running (7.5% compared to 4% for the props). However, the findings of Docherty and colleagues (1988) were based on only 40 minutes of a full game, with little explanation as to how the data were extrapolated to provide information on 80 minutes of play. Additionally, McLean (1992) analysed data from televised footage, which potentially limited its analysis accuracy, as some important match plays would likely to have been missed due to restrictions on of the extent of the coverage. Moreover, neither Docherty et al. (1988) nor McLean (1992) reported any reliability information on the systems used, casting some doubt on the accuracy of the findings.

2.5.2 Professional Era

Subsequent to its professionalization, Hughes and Blunt (1998) suggested that rugby union had become more of an "open" game owing to the reduction in scrums and the greater number of sprints. Accordingly, in one of the few investigations to compare the pre- and post-professional eras in rugby union, Eaves and Hughes (2003) reported ruck frequency increased two-fold in the professional era, suggesting the game had moved away from being dominated by maul play towards a more ruck dominated game. It was suggested that this was indicative of a "faster, more expansive game involving significantly more back play" (Eaves & Hughes, 2003, p. 109), following which had implications for both the technical and physiological demands of the game (Eaves & Hughes, 2003). Consequently, a growth in the investigations of the physical demands of rugby union players, in both the northern and southern hemispheres, occurred.

Numerous authors have utilised time motion video analysis (both manual cameras and semi-automated systems) to investigate the locomotive movement patterns of rugby union players. Primarily the findings established that the backs cover greater distances than forwards. Although varying total distances have been portrayed across studies, averaging from 5,640 m to 4,240 m for U19s (Deutsch et al., 1998), 6,095 m to 4,662 m for elite players participating in the southern hemisphere (Austin et al., 2011b), 6,127 m to 5,581 m for elite northern hemisphere players (Roberts et al., 2008) and 6,300 m to 5,400 m (Quarrie et al., 2013) and 7,944 m 7006 m (Lacome et al., 2014) for international players (backs and forwards, respectively). However, such disparities (more than 2 km when comparing certain investigations) could be attributed to the differing study designs, particularly with respect to the number of athletes analysed (20 and 29 for the southern and northern hemisphere studies, correspondingly, and 763 international players), the duration of the matches analysed (ranging between 40 minutes of match play to full matches), the equipment used, and the manner in which the data has been presented (frequencies, percentages, ratios). Indeed, incomplete presentation of the data can often lead to the findings being misinterpreted and incorrect conclusions being drawn from it (Hughes & Bartlett, 2002).

Nonetheless, the larger distances travelled by the backs has been attributed to their involvement in greater walking distances (Deutsch et al., 1998; Deutsch et al., 2007; Duthie et al., 2005; Roberts et al., 2008), averaging 28 - 34% in comparison to 15 - 20% for the forwards when competing in southern hemisphere leagues (Deutsch et al., 1998; Duthie et al., 2005). This was supported by the work of Roberts et al. (2008) who calculated that the backs covered 2,351 m walking whereas forwards typically covered 1,928 m when playing in the English Premiership. Similarly, at the international standard, the wing positions were found to travel the greatest distances walking (1,100 m) and the hooker the least (750 m). These figures lend support to the theory that the backs are required to continually re-adjust their positioning in an attempt to try and find space to run into (Deutsch et al., 2007). Conversely, the forward positions spend greater time and cover further distances whilst at a jogging speed, characteristically ~ 19 - 22% compared to ~ 17% for the backs (Deutsch et al., 1998; Deutsch et al., 2007; Duthie et al., 2005). At the international standard Quarrie et al. (2013) also found that props and hookers spent the greatest duration at speeds of jogging (9 minutes 59 seconds and 9 minutes 41 seconds respectively), which could reflect the nature of their game, primarily to follow play, moving between breakdowns to assure the ball is secured. However, Roberts et al. (2008) did not reveal any significant differences in distances between the forward and back positions when moving at speeds classified as jogging and reported the most distance covered at this speed was by the inside backs positions (2,094 m). The discrepancies across the literature however, could signify either a difference in northern and southern hemisphere rugby demands, the international and non-international professional game or could be owing to the inconsistent speed classification of "jogging" across the studies.

Sprint ability in rugby union is believed to be an essential aspect of the game (Duthie, Pyne, Ross, Livingstone & Hooper, 2006), with an understanding of the frequencies, durations and distances covered being of paramount importance for training and match preparation purposes. Researchers are in agreement that the back positions are required to perform substantially more sprint efforts than the forward positions, ranging between 14 and 20 sprints per game across the northern and southern hemisphere (Deutsch et al., 2007; Duthie et al., 2005; Eaton & George, 2006), with the outside backs particularly shown to cover the greatest distances (280 m) across all positions while sprinting (Roberts et al., 2008). However, Austin, Gabbett and Jenkins (2011a) found sprinting demands had increased two-fold and reported, on average, players performed 40 sprints per match, which was suggested to be indicative of a faster game (Austin et al., 2011a) when compared to findings reflective of the 2000 - 2001 season (Deutsch et al., 2007; Duthie et al., 2005). Further discrepancies are evident in the duration of sprinting, with mean durations reported to be ~ 3 seconds for backs and ~ 2 seconds for the forwards in the southern hemisphere (Deutsch et al., 2007; Duthie et al., 2005; Duthie et al., 2006) and 1.2 - 1.9 seconds for the back positions and ~ 1 second for the forwards in the northern hemisphere (Eaton & George, 2006; Roberts et al., 2008). Further variations were displayed at the international standard whereby Quarrie et al. (2013) showed that backs spent as much as 16 seconds sprinting where as it was 7 seconds for the forwards, much longer than previously reported. However, the contrasting methods of determining a 'sprint' could explain this difference, as principally researchers assessing southern hemisphere competition have used subjective measures to classify a sprint established by visually identifying locomotive movement based on descriptors (Austin et al., 2011a; Deutsch et al., 1998; Deutsch et al., 2007; Duthie et al., 2005), whilst a predetermined objective speed zone has been used on data from the northern hemisphere (Eaton & George, 2006; Roberts et al., 2008), albeit based on arbitrarily selected absolute speed.

Whilst sprint ability and repeated sprint ability is crucial in team sports (Spencer, Lawrence, Rechichi, Bishop, Dawson & Goodman, 2004), within contact sports it is rather a player's ability to perform repeated high intensity activity (i.e. high intensity running, sprinting combined with static exertions including scrums, rucks, mauls, tackles) that is critical (Gabbett, 2012). In rugby union however, there is limited literature that has reported on the repeated high-intensity activity efforts in rugby union match play (Austin et al., 2011a; Jones et al., 2015). Austin et al. (2011a) reported repeated high-intensity activity efforts occur on average between 2 - 21 times per match and can range between 28 - 52 s in duration depending on position. Mean scores were determined as 15 ± 3, 17 ± 4, 16 ± 2, 7 ± 3 for the front row forwards, back row forwards, inside backs and outside backs respectively. Similarly, Jones et al. (2015) found the mean frequency of repeated high-intensity efforts to be 11 ± 8, 13 ± 7, 7 ± 7, 6 ± 6 for the tight forwards, loose forwards, inside backs and outside backs respectively; therefore with the exception of the inside backs, not too dissimilar. Whilst the findings of Jones et al. (2015) were lower than Austin et al (2011a) this could be due to the use of GPS to determine repeated high-intensity efforts compared to TMA methods (Austin et al., 2011a) whereby a 'sprint' was determined based on subjective locomotive descriptors. However, there was no obvious reason for the disparity in the findings for the inside back positions. It could however, again, be owing to the difference in methodologies used, or potentially could be indicative of the players analysed. Both investigations used data from one team and although relatively large data sets were presented, the finding could be more reflective of individual players or team tactics rather than to the demands of the game per se. Nonetheless, Austin et al. (2011a) further reported the front row forwards can participate in a range of 10 - 24 different exercises per bout over a period of 118 s. Typically, the front and back row forwards spend longer durations in repeated high intensity activity bouts (45 s and 52 s, respectively) owing to their greater involvement in scrums, rucks and mauls in comparison to the inside (26 s) and outside backs (28 s) (Austin et al., 2011a). Repeated high intensity activity were characteristically dominated by sprinting activity for the inside and outside backs (45%), compared to tackling for the front row and back row forwards (36% and 35%, respectively) (Austin et al., 2011a). However, aside from Austin et al. (2011a) few other investigations have been carried out to substantiate these findings and whether they provide a true representative of the worldwide game and the English Premiership.

The intensity at which a player performs is believed to be one of the most important factors in determining match demands (Mohr et al., 2003) as it is assumed to be a good indicator of the physiological demands placed on the athlete (Bangsbo et al., 1991). Accordingly, the amount of high intensity "work" (high intensity running, sprinting and static exertions) performed is often analysed. The forwards' positions are believed to be the ball winners in the game

(Deutsch et al., 2007; Eaton & George, 2006) and are primarily required to contest for possession in set pieces (scrums and lineouts), in rucks and at the tackle (Quarrie et al., 2013), which is reflected in their greater involvement in static exertions, particularly rucks, mauls, scrums and tackles compared to the back positions. On average, the forwards spend around 3 minutes longer in static exertions than the backs (Quarrie et al., 2013) at the international standard, with mean single durations reported as ~ 4.15 s for forwards compared to 2.21 s for backs (Lacome et al., 2014). Similarly, in the southern hemisphere domestic league Austin et al. (2011b) reported the front and back row forwards typically spend ~ 9.54 and 10 minutes in static exertion compared to 2.45 and 2 minutes for the inside and outside backs, respectively. However, whilst the findings of Roberts et al. (2008) illustrated the mean duration of static efforts were 5.2 s for the forwards and 3.6 s for the backs in the English Premiership, the findings of Austin et al. (2011b) displayed larger durations for the forward positions, reporting mean durations for static efforts of 11 s for the front row positions and 15 s for the back row in the southern hemisphere. Similar findings were displayed when the percentage of time was investigated; in the southern hemisphere teams the forwards were reported to spend between 12% – 14% in high intensity activity (Deutsch et al., 1998; Deutsch et al., 2007; Duthie et al., 2006) and the backs ranging between 1.3% and 8% (Deutsch et al., 1998; Deutsch et al., 2007; Duthie et al., 2006). In the northern hemisphere teams, forwards were found to spend 14% of the game in high intensity and the backs 6% (Roberts et al., 2008), with Eaton and George (2006) reporting that the loose forwards spent the greatest proportion of the game in high intensity activity (12%) and the outside backs the least (6.5%). However, the more recent findings of Austin et al. (2011b) suggest that the demands of the contemporary elite game may have changed since then with a greater duration of match play being spent in high intensity activity compared to earlier findings from the Super 12s 2001 - 2002 season, ranging between 21% for the front row forwards to 14% for the outside backs, which is substantially larger than had been previously reported. A constant, however, was that a lower percentage of time was spent in high intensity activity for the backs compared to the forwards. Further investigation of the contemporary game is warranted.

Researchers concur that the forward positions are involved in more static exertions, ranging (in the southern hemisphere) between 59 - 66 efforts per game compared to 9 for the back positions (Deutsch et al., 2007; Duthie et al., 2005). For northern hemisphere players, the values have been found to be higher, with Roberts et al. (2008) reporting on average 89 and 24 efforts per game for the forwards and backs, respectively whilst ~ 53 static bouts for international players have been reported (Lacome et al., 2014). However, investigations have highlighted that static exertion duration and frequency varies within positional groups. Deutsch et al. (2007) suggested specifically that the roles of the front row and back row forwards differed in that the primary role of the front row was to develop the platform for attack and defence, whereas the demands of the back row were most similar to back-line players, being responsible for the offensive and defensive plays within the game. This was possibly shown through the front row attending significantly more rucks and mauls (almost 25% more) than the back row forwards (Deutsch et al., 2007) whilst the front row and lock positions attended a greater number of rucks in comparison to the flankers and number 8 positions at the international standard (Quarrie et al., 2013).

Whilst researchers have shown backs cover the largest distances and perform the most sprints, the greatest amount of work is believed to be performed by the forward positions owing to their superior involvement and longer durations spent in static exertions, hence yielding higher work to rest ratios (W:RR). Researchers have reported W:RR to range between 1:4 - 1:7 for the front row forwards (Austin et al., 2011b; Deutsch et al., 2007; Duthie et al., 2005), between 1:4 - 1:8 for the back row forwards (Austin et al., 2011b; Deutsch et al., 2007; Duthie et al., 2005; Eaton & George, 2006), between 1:15 - 1:21 for the inside backs (Deutsch et al., 2007; Duthie et al., 2005), and the 1:14 – 1:23 for the outside backs (Deutsch et al., 2007; Duthie et al., 2005; Eaton & George, 2006). However, Austin et al. (2011b) reported higher work rates for the inside and outside backs than had previously been found (W:RRs - 1:5 and 1:6, correspondingly), although this could reflect the increased frequency of sprints recorded by Austin et al. (2011b) for the backs or be typical of the particular team analysed and thus imitate their specific playing patterns and demands.

From the aforementioned investigations it is evident that researchers have predominantly tended to group positions where possible. Often, all the forward positions are grouped as one, as are the back positions, and then further frequently divided into the tight forwards, loose forwards, inside/midfield backs, and outside backs/wingers (Austin et al., 2011a; Austin et al., 2011b; Deutsch et al., 1998; Deutsch et al., 2007; Docherty et al., 1988; Duthie et al., 2005; McLean, 1992; Roberts et al., 2008) with little reference to individual positional demands. Whilst to-date researchers have often tended to group all positions together, typically due to the relatively small data sets analysed, in doing so some discrepancies have been reported (Eaton & George, 2006; Quarrie et al., 2013). For example, amongst the forward positions significant differences were displayed across a number of performance indicators, namely that the props and locks had significantly greater involvements in the lineout than the hooker, flankers and number 8 positions (Eaton & George, 2006). Substantial differences were portrayed specifically between the props and flanker positions when distances travelled at difference speed classifications were investigated (Quarrie et al., 2013). Previously, researchers have grouped hookers with loose forwards based on anecdotal evidence of similarity in positions, however, the findings of Quarrie et al. (2013) suggested the position of the hooker is most like the lock and prop positions rather than the loose forwards. Similarly, distinct differences were also evident within the back positions (Quarrie et al., 2013) - particularly the scrum and fly half positions - in terms of the frequency of kicks, kicks received and number of passes. The findings demonstrated the scrum half position has one of the most demanding movement loads, covering the greatest distances whilst the ball is active (4,500 ± 280 m). However, there is currently a paucity of analyses conducted by individual position and further investigation in this manner is justified. This said, in certain instances there is still a need to combine positions and positional groups in the same manner as in previous analyses. This will not only enable comparisons to continue to be made with earlier work and help identify any significant changes in the demands over time, but also will be useful to practitioners should they want to have a general understanding of the demands, for instance, for the forwards or front row forwards for training purposes.

Overall, the research to-date suggests that modern rugby union is typically dominated by low intensity activity, interspersed with higher intensity efforts (Austin et al., 2011a; Austin et al., 2011b; Deutsch et al., 1998; Deutsch et al., 2007; Duthie et al., 2005; Eaton & George 2006; Roberts et al., 2008). However, it is apparent that the demands of the game vary between playing positions, across forwards and the backs, and even within positional groups (Austin et al., 2011a; Austin et al., 2011b; Deutsch et al., 1998, Deutsch et al., 2007; Duthie et al., 2005; Duthie et al., 2006; Eaton & George, 2006; Quarrie et al., 2013; Roberts et al., 2008). Therefore, future investigations focusing on quantifying performance should incorporate player position as an independent variable in the analysis (Eaton & George, 2006; Hughes et al., 2012; Quarrie et al., 2013). Yet difficulties occur when trying to consolidate the existing findings as direct comparisons across studies are prohibited owing to the variations in study designs, the classification of movements (e.g. what constitutes 'high intensity activity') and the choice of dependent variables (such as being expressed as units of time, percentage or frequencies).

Whilst TMA methods have been used by many researchers to accurately determine the demands of the game, such techniques are not without limitations, including the lengthy process of analysing the information post-match (Barris & Button, 2008). A five-hour post-match process per player has previously been reported by Roberts et al. (2008), which could explain why some researchers have chosen to analyse only half a match or less (Deutsch et al., 1998; Roberts et al., 2008) or perhaps why small sample sizes have been used. Consequently, extrapolation of such data to a full match could potentially under- or over-estimate the actual match demands. Other sources of error can arise owing to the sheer complexity of the game (McLellan et al., 2011b) (for example, the playing tactics of the opposition or the uncontrollable external factors such as the weather), the employment of numerous analysts (operators), and the inability to report much information in real-time (McLellan et al., 2011b). In recent years, however, as technology has developed, the use of GPS has become widely available as an alternative method for analysis of sport performance, particularly within team sports, predominantly due to the ease of use and its ability to capture large quantity of data real time from a number of athletes.

2.6. Global Positioning Systems Time Motion Analysis (GPS)

2.6.1 Global Positioning Systems (GPS)

Global positioning systems (GPS) originated as a military tool for the U.S. Department of Defence (Townshend, Worringham & Stuart, 2008). It incorporates a constellation network of 27+ satellites orbiting the earth at 11,000 nautical miles, which became available for civilian use in the mid-1990s. Each satellite emits a unique coded radio signal to a GPS receiver on earth, from which position, time, distance and speed can be attained (Townshend et al., 2008). Precision and accuracy is related to the horizontal dilution of position (HDOP) and it is thought that the GPS receiver must receive signals from at least 4 satellites to gain accurate coordinates (Jennings, Cormack, Coutts, Boyd & Aughey, 2010). The HDOP reflects the geometrical positioning of the satellites and such an arrangement is said to affect the accuracy and precision of the information received (Jennings et al., 2010). The HDOP values range from 1- 50 dilution of precision value, with 1 being the most accurate and 50 the least. The greatest accuracy is obtained when satellites are situated directly above the area of use and the remaining satellites spread equally around (Witte & Wilson, 2004).

The receiver decodes the individual signals and measures the distance travelled from each satellite, multiplies the distance by the speed of light (the speed at which the signal travels) and through the use of trigonometry, determines position (Schutz & Herren, 2000; Townshend et al., 2008). In addition, the GPS receivers are capable of measuring speed. There are a number of suggested methods to calculate speed, with the most popular in commercially available devices being through the Doppler Shift method. It is measured by the rate of change in the radio frequency signals associated with movement away or toward the orbiting satellite (Schutz & Herren, 2000).

Originally the U.S. Department of Defence included deliberate random errors in the system to alter the atomic clocks (Schutz & Chambaz, 1997), which reduced the accuracy of the data received and precision of positional information, to limit any advantage of opposing attackers, which was known as 'selective availability' (SA) (Macleod, Morris, Nevill & Sunderland, 2009; Schutz & Herren, 2000; Townshend et al., 2008; Witte & Wilson, 2004). To overcome the inaccuracies posed by 'selective availability' a number of methods were developed to increase the accuracy of the data received (Witte & Wilson, 2004). The most pertinent of these approaches was the 'differential' GPS (dGPS).

Differential global position systems developed a fixed satellite and positioned it at a known location to allow the pseudo distances to be measured, enabling the necessary corrections to be made and transmitted (Schutz & Herren, 2000). Researchers reported that the dGPS was a relatively valid tool for measuring human movement (Larsson & Henrijsson-Larsén, 2001; Schutz & Herren, 2000; Terrier, Ladetto, Merminod & Schutz, 2001), particularly in measuring speed, distance and positions. Acceptable measurements of speed (during walking and through to running) were evident via CVs in the range 0.83% – 1.38% (Schutz & Herren, 2000). Additionally, satisfactory values of distances were found with researchers recording measurements to be within 0.8 m of actual distance and 0.6 m of position (Larsson & Henrijsson-Larsén, 2001). Yet, the weight and size of the dGPS devices were not very conducive for practical use in sports, with participants required to wear antennas to receive a signal (Schutz & Herren, 2000). However, in the year 2000 selective availability was turned off to allow better precision for civilians and subsequently resulted in an increase in the use of non-differential GPS and a spate of investigations validating their use in sporting environments.

Early reports were in agreement that non-differential GPS could be used to report speed (Townshend et al., 2008; Witte & Wilson, 2004), distance, and positioning relatively accurately, although it was dependant on the course and speed of travel (Townshend et al., 2008). When speed was recorded in linear motion, 90.8% and 97.9% of the results were within 0.1 $m{\cdot}s^{-1}$ and 0.2 $m{\cdot}s^{-1}$ of chronometry values when running at speeds of 1.06 - 9.62 $m{\cdot}s^{-1}$, respectively (Townshend et al., 2008). During cycling at quicker speeds (15 - 35 $km{\cdot}h^{-1}$), 82% of speed values fell within 0.4 $m{\cdot}s^{-1}$of the chronometry values. Further reductions in accuracy were evident when negotiating a curve, with the GPS tending to underestimate speed (Townshend et al., 2008; Witte & Wilson, 2004). Indeed, Witte and Wilson (2004) reported only 16% of speed values to be within ± 0.4 $m{\cdot}s^{-1}$ and 28% within ± 0.2 $m{\cdot}s^{-1}$ of actual speed when travelling around a radius of 10 m, whereas Townshend et al. (2008) found 71.1% and 86.7% of speed values were within 0.1 $m{\cdot}s^{-1}$ and 0.2 $m{\cdot}s^{-1}$ of the chronometry measurements, correspondingly, over the same radius. The disparities in values could be owing to one investigation analysing sprint running (Townsend et al., 2008) and the other cycling (Witte & Wilson, 2004), whereby tighter leans around the bend were a factor, and that the subjects wore an antenna on their heads whilst cycling to allow for a better satellite signal. In terms of other parameters, whilst Townshend et al. (2008) found GPS could accurately measure distance covered in a straight line (recording a mean value of 100.46 ± 0.49 m when forty trials over 100 m were analysed), Witte and Wilson (2004) highlighted large inadequacies in measuring accelerations and decelerations when rapid changes occurred, therefore reducing its validity for use in sports. Both studies used a 1 Hz sampling rate, which could explain the poor validity observed as only one measurement is recorded each second and therefore some important measures are potentially missed. Moreover, limitations and practicality issues were apparent for uses within a sporting context, particularly within contact sports as the weight of the units could range from 1.1 kg to 4 kg (Larsson & Henrijsson-Larsén, 2001; Schutz & Herren 2000; Terrier et al., 2001). Schutz and Herren (2000) reported that to ensure the subjects could reach maximum velocity the equipment had to be carried in a convertible car alongside the testing area whilst the design of numerous GPS units required participants to wear antennae on a head piece (Schutz & Herren, 2000; Witte & Wilson, 2004; Townshend et al., 2008).

2.6.2 Commercially Available GPS Devices

With an increased interest in using GPS in sporting settings to provide data and allow real time analysis (Edgecomb & Norton, 2006) smaller and lighter devices have become available, enabling players to wear GPS units in a padded harness just below the neck (between the scapulae) for ease of movement. In team sports, two leading brands have emerged in regular use (GPSports, Canberra, Australia and Catapult, Melbourne, Australia). Such units have the ability to measure speed, time, altitude, distance, heart rate and the percentage of time spent in different heart rate and speed zones (Edgecomb & Norton, 2006). Additionally, developments of devices have also seen tri-axial accelerometers incorporated into the units (GPSport - SPI Elite, Wi SPi, SPI Pro; Catapult – minimaxX; VXsports), increased frequency rates (1 Hz, 5 Hz, 10 Hz, and 15 Hz), and a gyroscope (measuring angular motion and rotation) to determine the demands of sports.

As the sampling rate of GPS devices has increased, their accuracy in determining speed and distance travelled during team sports has increased (Barbero-Alverez, Coutts, Granda, Barbero-Alvarez & Castagna, 2010; Coutts & Duffield, 2010; Edgecomb & Norton, 2006; Gray, Jenkins, Andrews, Taaffe & Glover, 2010; Jennings et al., 2010; Johnston, Watsford, Pine, Spurrs, Murphy & Pruyn, 2012a; MacLeod et al., 2009; Petersen, Pyne, Portus & Dawson, 2009), although it is still dependent on the path taken, at what speed and over what distance. Moreover, there remains inconsistency in the published literature, with a number of studies suggesting different GPS devices underestimate true values, whilst others overestimate.

2.6.3 Reliability and Validity of GPS

2.6.3.1 Reliability and Validity of Locomotive Measurements

In the main there is consensus among researchers that the greater the sampling frequency, the higher the accuracy of devices. The earliest GPS devices captured movement data at a sampling frequency of 1 Hz (including GPSports models SPI 10, SPI Elite, Wi SPS Elite and Catapult MinimaxX), but whilst they were capable of measuring speed and distance relatively accurately at low running speeds and over longer distances, it was (is) considered that this diminished when players move at higher running speed (> 20 $km \cdot h^{-1}$) and over shorter distances (< 20 m). Furthermore, findings have been seen to be dependent on the GPS model used and even then discrepancies in the findings protrude. For example, when investigating one of the earliest models, the Sports Performance Indicator (SPI 10) (GPSports, Canberra, Australia), Edgecomb and Norton (2006) reported that, on average, it overestimated distance by 4.8% (when tested over 59 trials) in comparison to computer-based tracking. Conversely, both Coutts and Duffield (2010) and Petersen et al. (2009) reported it had acceptable validity in determining total distance but reported the SPI 10 significantly underestimated distance by ~ 5%, depending on the velocity. Whilst Coutts and Duffield (2010) showed moderate reliability when measuring total distance and peak speed (6.7% & 5.8% respectively), its poor reliability at high intensity and very high intensity running speeds were identified producing CVs of 32.4% and 30.4% correspondingly.

The SPI Elite GPS models, sampling at 1Hz have been found to improve performance and have been reported as a valid measure of distance, with Duffield, Reid, Baker and Spratford (2010) reporting no notable differences between the criterion measure (VICON motion analysis system, 100 Hz) at slow running speeds, although they found it significantly underestimated distance at faster speeds (~ 4 m) over 26 m. This concurred with the findings of Coutts and Duffield (2010), who noted it underestimated distance by 2.0 ± 3.7% when tested over a circuit involving walking, jogging, fast running and sprinting. Duffield et al. (2010) also reported higher disparities were evident when confined to a 2 - 4 m tennis court space (~ 13.9 – 10.9 m, respectively), therefore questioning its capability of determining movement patterns accurately in team sports when confined to a pitch area. Nonetheless, mean and peak speeds recorded by SPI Elite devices have been highly correlated against those of timing gates ($r = 0.99$) (Barbero-Alverez et al., 2010; Macleod et al., 2009), although a higher correlation was evident when sprints were carried out over longer distances; 30 m ($r = 0.94$) compared to 15 m ($r = 0.87$) (Barbero-Alverez et al., 2010). Yet, as noted earlier utilising the relationship measurement alone to validate speed is not a suitable evaluation (Bland & Altman, 1986). Similar to the SPI 10, whilst good reliability was shown at lower running speeds (4.13%) moving at very high intensity running speeds (> 20 km·h^{-1}) displayed larger CVs (15.4%; Coutts & Duffield, 2010). Moreover, test-retest reliability of the devices was found to be good, displaying a CV of 1.2% (Barbero-Alverez et al., 2010), although Duffield et al. (2010) suggested the SPI Elite devices could not be used interchangeably due to the large CVs produced (up to ~ 27% for peak speed).

In agreement with Coutts and Duffield (2010), Gray et al. (2010) found the Wi SPI Elite GPS devices were a valid tool for measuring straight line locomotive movement irrespective of speed, reporting distances to be typically overestimated by ~ 4 m over a 200 m course. Although identified its validity was reduced when negotiating non-linear courses typically underestimating distance between 1.1 m to 19.6 m dependant on movement speed. The Wi SPI Elite showed acceptable reliability reporting intra-receiver CVs to range between 1.85% - 2.71% for walking through to sprinting in a linear motion and inter-receiver from 1.46% – 3.38%, and likewise when negotiating a non-linear path (intra – 1.98 – 2.79% ; inter – 1.63 – 3.43%) at speeds of walking, jogging and running. However, the findings illustrated poorer reliability when sprinting, displaying intra- and inter- reliability of 4.80% and 6.04%, respectively (Gray et al., 2010).

When investigating an alternative manufactured device, Jennings et al. (2010) found the Catapult MinimaxX GPS devices also underestimated distance when short sprints were performed, irrespective of whether they occurred in a straight line, incorporated changes of directions or when negotiating a team sports circuit. Against a criterion measure, distance was underestimated by as much as 32.4 ± 6.9% over a 10 m stretch when sprinting, but validity increased with distance regardless of speed (~ 9 – 12% from walking to sprinting over 40 m). Jennings et al. (2010) reported poor reliability in straight line running when striding or sprinting short distances (≤ 10 m), with CVs of up to 77.2% for sprinting. Yet, reliability improved when gradual and tight changes of direction were performed whilst striding (10.8%) and sprinting (12.0%). However, it was suggested that this was owing to the lower movement speeds executed when negotiating the changes of direction. Therefore, in general, researchers are in agreement that practitioners should be conscious of such errors when interpreting data from a GPS sampling at a 1 Hz frequency, as vital information may be lost due to its limitations in detecting changes particularly over short distances and at high running speeds.

As device sampling rate increased to 5 Hz, errors have been shown to be less pronounced in comparison to 1 Hz devices (Barbero-Alverez et al., 2010; Jennings et al., 2010; Johnston et al., 2012a; Petersen et al., 2009; Waldron, Worsfold, Twist & Lamb, 2011a). However, limitations are still evident when attempting to determine distances and speeds over shorter ranges (< 20 m) and whilst moving at higher running speeds (> 20 $km \cdot h^{-1}$), particularly with the Catapult model. The validity of the Catapult devices was deemed acceptable for longer distances at speeds up to striding (5 $m \cdot s^{-1}$), typically overestimating distances by 0 - 3% (Petersen et al., 2009). However, validity decreased at higher running speeds of sprinting, underestimating the criterion measures by as much as 24% (Petersen et al., 2009). Better reliability in detecting straight line running was determined compared to 1 Hz devices, with CVs of up to 39.5% for sprinting compared to 77.2% when using 1 Hz devices and ~ 9% for striding and sprinting when completing a change of direction course (Jennings et al., 2010). Likewise, Petersen et al. (2009) found reliability was greater over longer distances and slower speeds (< 4%) although notably less so when sprinting (< 20 m), with CVs ranging between 4% - 43%. In accordance Johnston et al. (2012a) found the 5 Hz Catapult device to be a valid and reliable measure of total distance (% TEM < 5%) and average and peak speed (% TEM between 5 - 10%), reporting no statistical differences against criterion measures when tested over a team sport simulation circuit (1,305 m). Similarly, Johnston et al. (2012a) acknowledged its reduced ability to validly and reliably report distance and speed as movement intensity increased.

Investigations into the GPSports SPI Pro (5 Hz) device typically reported that it was reliable and valid when covering long distances (600 - 8,800 m) at speeds of up to striding, yet limited when performing shorter sprint efforts (Petersen et al., 2009). Acceptable validity values of 0.4 - 3.7% were illustrated when walking (≤ 7.2 $km \cdot h^{-1}$) to striding (14.4 - 18 $km \cdot h^{-1}$) (Petersen et al., 2009) and good reliability was reported (TE < 4%) when moving at walking to striding pace (Barbero-Alverez et al., 2010). Greater errors were evident when sprinting (> 18 km·h^{-1}) over 20 – 40 m with, the SEE ranging between 3 and 11% (Petersen et al., 2009). The SPI Pro devices were found to underestimate distances from 1 – 4% when moving at speeds up to striding (14.4 – 18 km·h^{-1}), with larger underestimation in distances when sprinting (> 18 m·s^{-1}), ranging between 6 – 20%. Therefore, the system seems to be limited when measuring short sprints, but is substantially more accurate than the MinimaxX 5 Hz device (4 – 43%; Petersen et al., 2010). In addition, Waldron et al. (2011a) found both speed and distance over the shorter distances of 10 m, 20 m, and 30 m were underestimated (CV < 10%). Reliability was reported to be acceptable for both distance (CV 1.8% – 2.3%) and speed (CV 1.6% – 2.1%), with improved reliability as distance increased. Waldron and co-authors further revealed the GPS SPI Pro 5 Hz was most consistent in detecting peak speed (CV 0.78%). Moreover, although insufficiencies in its ability to reliably detect frequencies of accelerations, particularly over 30 m (CV 14.1%) were displayed, acceptable reliability in recording peak accelerations between 10 m – 30 m (CV 5.01% - 5.16%) were reported.

The recent advancements in GPS have seen sampling rates increase to 10 Hz (Catapult devices) and 15 Hz (GPSports devices) with greater validity and accuracy expected. Castellano, Casamichana, Calleja-González, Román & Ostojic (2011) reported the Catapult MinimaxX (v. 4) sampling at a 10 Hz frequency increased the validity of GPS devices, particularly in detecting distances over 15 m and 30 m (13.2 ± 1.4 m and 28.1 ± 1.4 m respectively). Reliability was also improved, with typical errors of 0.2 m over 15 m trials and 0.3 m for 30 m trials. Similar to devices with lower sampling rates, Castellano et al. (2011) found improved accuracy as distances increased, for 30 m (SEE, 5.1%) in comparison to 15 m (SEE, 10.9%). Additionally, only small disparities between units of the same model (CVs; 15 m – 1.3% and 30 m – 0.7%) were demonstrated, suggesting they could be used interchangeably (Castellano et al., 2011). Moreover, Johnston, Watsford, Kelly, Pine and Spurrs (2014a) reported increased validity and reliability when 10 Hz and 15 Hz devices were investigated. In particular, their analysis illustrated that the 10 Hz (Catapult) device was a valid method in determining total distance, with a difference of less than 1% observed compared to the criterion measure. Both devices were identified as reliable in measuring total distance (TEM < 1.9%) however, showed reduced levels of reliability when moving at very high intensity speeds (> 10%). Whilst overall the 10 Hz Catapult devices were seen to be favourable over the 15 Hz GPSport device in determining total distance and peak speeds accurately and reliably, in a recent study by Vickery, Dascome, Baker, Higham, Spratford and Duffield (2014) comparing 5 Hz, 10 Hz (Catapult) and 15 Hz (GPSports) devices, no effect of sampling rate was demonstrated in terms of the accuracy of speed or distance. Moreover, no significant differences were observed between the criterion measure (VICON motion analysis system) and the distances covered, or with mean and peak speeds. Nonetheless, there was a deficit of 13-14% in the distances covered across the three GPS devices compared to the criterion, and again, their reliabilities were reduced at high running speeds over short distances (CV ranging between 3-33%).

2.6.3.2 Tri-axial Accelerometers

The tri-axial accelerometers encapsulated within GPS devices are motion sensors capable of simultaneously measuring movement in three perpendicular axes (Krasnoff, Kohn, Choy, Doyle, Johansen & Painter, 2008). Developments in technology have seen these incorporated into the latest available versions of GPS devices (GPSport - SPI Elite, Wi SPi, SPI Pro; Catapult – MinimaxX; VXsports), whereby movements, accelerations and decelerations ($m \cdot s^{-2}$) can be measured in reference to gravitational forces, quantifying accelerations and decelerations as “G” forces (equating 9.81 $m \cdot s^{-2}$ to 1 G; McLellan & Lovell, 2012). With such potential, practitioners have become increasingly interested in utilising these devices to determine impact measurements in team sports (Austin et al., 2011b; Cunniffe et al., 2009; Duthie et al., 2003; Dwyer & Gabbett 2012; Gabbett, 2013a; McLellan, Lovell & Gass, 2011a; McLellan et al., 2011b; McLellan & Lovell, 2012). The combination of the tri-axial accelerometers and GPS could potentially provide invaluable information on the sustained body loads (Kelly, Coughlan, Green & Caulfield, 2012) that occur during training and competition, and provide further insight into the onset and development of fatigue (Aughey, 2010; Boyd, Ball & Aughey, 2011). Moreover, the ability to measure objectively and accurately the stressors placed on the body during competition and training could be paramount for the reduction of injury, particularly in contact sports such as rugby union (Duthie et al., 2003; Takarada, 2003). Such information would enable practitioners and medical teams to monitor training and match loads objectively and establish protocols and procedures, which, in principle, enhance desirable performance qualities at the same time as minimising negative risks. However, although a number of GPS devices now have these capabilities for team sports (Carling et al., 2008), little evidence exists on the reliability and validity of the information they provide (Tran, Netto, Aisbett & Gastin, 2010; Wundersitz, Gastin, Richter & Netto, 2010; Boyd et al., 2011; Waldron et al., 2011a; Kelly et al., 2012).

The "G" force measurements produced by the GPS devices are typically formulated via an in-built algorithm. Whilst many manufactures do not disclose the algorithms used to protect their commercial rights, the manual manipulation of one device, GPSports product SPI Pro (5 Hz), yields the equation:

$$Vm = \sqrt{a^2+b^2+c^2}$$

(where Vm = vector magnitude, a = left/right movement, b = forward/back movement, c = vertical movement)

and the Catapult devices:

$$\text{Vm (expressed as player load)} = \frac{\sqrt{(a_{y1} - a_{y-1})^2 + (a_{x1} - a_{x-1})^2 + (a_{z1} - a_{z-1})^2}}{100}$$

(where a_y = forward acceleration, a_x = sideways acceleration, a_z = vertical acceleration; Boyd et al., 2011).

As such, authors have reported substantial differences in the acceptability of using GPS tri-axial accelerometers for providing accurate collision and body load data. It has been suggested that the reliability and validity of GPSports SPI Pro devices in quantifying collision impacts are questionable (Tran et al., 2010; Wundersitz et al., 2010). That is, in determining its reliability in identifying impact forces large CVs (as much as 30% and 22%) were reported for drop and counter movement jumps, respectively (Tran et al., 2010). Although Wundersitz et al. (2010) found moderate correlations (r = 0.45 – 0.62) between peak accelerations and ground reaction forces when running and changing direction over angles of 0°, 45°, 90° and 180°, Vm tended to over-predict forces. Accordingly, it has been argued in order to utilise the data from the SPI Pro devices smoothing techniques need to be employed to the raw data (Tran et al., 2010; Wundersitz et al., 2010). Alternatively, Kelly et al. (2012) proposed utilising artificial neural networks, which incorporate a wide range of information creating connections across the numerous different elements (Bishop, 1995; Kay, 2001) to determine pattern recognition from the accelerometer data. Albeit an extremely complex process, the intention here is to enable the detection of collisions, tackles, accelerations and decelerations in rugby union,

In contrast to the findings for the GPSports SPI Pro devices, Boyd et al. (2011) reported that the Catapult MinimaxX 2.0 accelerometers provided an acceptable level of reliability for measuring physical activity in team sports and was therefore capable of determining changes in physical activity. Following a laboratory test intra- and inter-device reliability were found to be acceptable (CVs of 0.9 - 1.05% and 1.02 – 1.04%, respectively), particularly in comparison to other accelerometers in use. Similarly, the between-device reliability was also found to be acceptable within field-based testing, yielding a CV of 1.94%, and a strong relationship was evident between devices (r = 0.996 – 0.999), albeit this does not a guarantee agreement and interchangeability between devices. Moreover, the findings demonstrated the noise (technical reliability) had a CV of < 2%, which was less than the smallest worthwhile difference (5.88%) and therefore revealed its capability in identifying differences in physical activity. However, only low accelerations were tested (0 - 3 G) and whilst determined suitable for Australian football, in rugby union and rugby league greater G forces have been recorded - as high as 10 G (McLellan et al., 2011b) during contacts (albeit only momentarily) - and even ~ 12 G when sprinting (Waldron et al., 2011a), which therefore begs the question whether its reliability would still be acceptable at higher impact forces. Furthermore, due to the disparities in the algorithms applied across the different models of GPS devices, the acceptable reliability of one model cannot be transferred across to other models and therefore the accuracy of the accelerometer data within different models need to be confirmed separately.

Gabbett et al. (2010) similarly reported favourable results on the capabilities of the Catapult MinimaxX devices in detecting collisions, as the in-built gyroscope recognised movement in a non-vertical state. The findings illustrated a strong correlation (r = 0.96) was present between the number of collisions automatically detected by the MinimaxX units and the number of collisions coded from video recording of the sessions (mild = 28 v 27, moderate = 37 v 41 and heavy 119 v 115 for video and GPS methods respectively), concluding that Catapult MinimaxX models could be used to measure contact loads during team sports (although they were unable to distinguish between attacking collisions and defensive collisions). However, as previously noted, the use of the correlation coefficient alone is not the most suitable measure to assess reliability and validity (Bland & Altman, 1986). Moreover, the identification of the contact variables were determined subjectively, therefore presenting the possibility of large error spans, with no indication as to how many operators were used and the intra- or inter-reliability test. Irrespective of whether one or more operators were used, it is questionable if these procedures were repeated whether the findings would be as favourable. The investigation would benefit from intra- and inter- reliability tests to ensure the consistency of data (variable) recognition.

2.6.4. Selection of Movement Classifications for GPS

The use of GPS software as the method of data capture has enabled users to identify pre-selected speed zones (6 categories) to measure different movement intensities during a match. Subsequently, researchers have typically assigned predetermined speed zones to identify different locomotive movement classifications. However, in the same manner as TMA investigations (as discussed in section 2.4, p. 36) researchers have selected an array of different speed zones to identify the same locomotive movements, hence causing inconsistencies within the literature, and indeed rugby union (Tables 2.8-2.14). Moreover, similar to TMA investigations, not only has the speed classifications used predominantly been absolute in nature, (i.e. the same classification across all positions), the categories often overlap and have also mainly been based on the methods outlined by Reilly and Thomas, (1976) and Bangsbo et al. (1991), dating back over twenty years. Whilst recently there have been attempts to address these inconsistencies and devise universal speed categories for different sports (Dwyer & Gabbett, 2012; Tables 2.12-2.13), these are still based on absolute speed zones. As with TMA investigations, attention should be paid to the speed classifications used and its impact on the interpretation of the results. Interestingly, so far little attention has been given to the impact different speed zones has on the quantification of work profiles of players, which clearly deserves further investigation (see Chapter 3 of this thesis).

Table 2.8 Locomotive speed classifications used in GPS investigations in Australian rules football.

Classifications in AFL	Wisbey et al. (2010)	Aughey (2010)	Coutts et al. (2010)	Brewer et al. (2010)	Mooney et al. (2011)	Johnston et al. (2012b)
	$km \cdot h^{-1}$	$km \cdot h^{-1}$	$km \cdot h^{-1}$	$km \cdot h^{-1}$	$km \cdot h^{-1}$	$km \cdot h^{-1}$
Low Intensity Speed	< 8	0.36 - 15	< 14.4			0 - 17
Moderate Intensity Speed						
High Intensity Speed	>18		>14.4		>15	> 17
High intensity efforts		15-35		> 15		
Standing			0-0.7			
Walking			0.7 - 7			
Jogging			7 - 14			
Running			14.4 - 20			
High Speed Running			20 - 23			
Sprinting			> 23	> 20		
No labels	< 8					
No labels	8 - 12					
No labels	12 - 16					
No labels	16 - 18					
No labels	> 18					
No labels	> 25					

*It is noteworthy that some boundaries (as published) overlap

Table 2.9 Locomotive speed classifications used in GPS investigations in rugby league (McLellan et al., 2011a, McLellan et al., 2011b).

Movement	$km \cdot h^{-1}$	Intensity Level	Definition
Walking	0 – 6	Low Intensity Running	Standing/Walking at low intensity, no flight phase associated with ambulatory movement in any direction
Jogging	6.1 – 12	Low Intensity Running	Running in any direction with minimal flight phase and minimal arm swing (1/4 pace)
Cruising	12.1 – 14	Moderate Intensity Running	Running in any direction with progressive acceleration and elongation of stride length with moderate arm swing (1/2 pace)
Striding	14.1 – 18	Medium Intensity Running	Running with increased velocity and arm swing (3/4 pace)
High Intensity Running	18.1 – 20	High Intensity Running	Running at near maximum pace (>85%) with near maximum stride length, stride frequency, and arm swing
Sprinting	> 20.1	High Intensity Running	Running with maximum effort

Table 2.10 Locomotive speed classifications used in GPS investigations in rugby league continued.

	Waldron et al. (2011b)	Austin & Kelly (2012)	Gabbett (2012)	Gabbett (2013a)
Movement	$km \cdot h^{-1}$	$km \cdot h^{-1}$	$km \cdot h^{-1}$	$km \cdot h^{-1}$
Standing		0 - 12		
Walking		0 - 12		
Jogging		0 - 12		
Cruising		12 - 14		
Striding		14 - 18		
High Intensity Running		18 - 20		
Sprinting		20 - 24		
High-Intensity sprinting		> 24		
Very low velocity			0 - 3.6	
Low intensity running	0.1 - 6.9		3.6 - 10.8	0 - 18
Moderate intensity running	7.0 - 13.9		10.8 - 18	
High intensity running	14.0 - 21.0	> 18	18 - 25.2	> 18
Very high intensity running/sprinting	> 21		> 25.2	

*It is noteworthy that some boundaries (as published) overlap.

Table 2.11 Locomotive acceleration classifications used in GPS investigations in rugby league and Australian rules football.

	Gabbett (2012)	Gabbett (2013a)	Johnston et al. (2012b)
	$m \cdot s^2$	$m \cdot s^2$	$m \cdot s^2$
Mild accelerations	0.55 - 1.11		
Moderate accelerations	1.12 - 2.78		
Maximal accelerations	> 2.79	> 2.79	> 2.78

Table 2.12 The calculated velocity ranges for 5 sports (Dwyer & Gabbett, 2012)

Velocity ranges ($km \cdot h^{-1}$)	Men's Soccer ($km \cdot h^{-1}$)	Women's Soccer ($km \cdot h^{-1}$)	Men's Field Hockey ($km \cdot h^{-1}$)	Women's Field Hockey ($km \cdot h^{-1}$)	AFL ($km \cdot h^{-1}$)
Stand	0.0 - 0.36	0.0 - 0.36	0.0 - 0.36	0.0 - 0.36	0.0 - 0.36
Walk	0.37 - 7.2	0.37 - 5.76	0.37 - 6.12	0.37 - 6.12	0.37 - 8.64
Jog	7.3 - 13.32	5.77 - 11.88	6.13 - 11.52	6.13 - 12.96	8.65 - 12.60
Run	13.33 - 21.6	11.89 - 19.08	11.53 - 20.16	12.97 - 19.08	12.61 - 20.16
Sprint	> 21.6	> 19.08	> 20.16	> 19.8	> 20.16

Dwyer & Gabbett (2012). Note: converted from $m \cdot s^{-1}$ to $km \cdot h^{-1}$

Table 2.13 Average locomotive speed categories for team sports (Dwyer & Gabbett, 2012)

Velocity ranges ($km \cdot h^{-1}$)	Stand ($km \cdot h^{-1}$)	Walk ($km \cdot h^{-1}$)	Jog ($km \cdot h^{-1}$)	Run ($km \cdot h^{-1}$)	Sprint ($km \cdot h^{-1}$)
Dwyer & Gabbett (2012)	0	0.72	7.56	12.96	20.16

Note: converted from $m \cdot s^{-1}$ to $km \cdot h^{-1}$

Table 2.14 Locomotive speed classifications used in GPS investigations in rugby union.

	Hartwig et al. (2011)	Cunniffe et al. (2009)	Coughlan et al. (2011)	Venter et al. (2011)	Reid et al. (2013)
Movement/Activity	Speed ($km{\cdot}h^{-1}$)	Speed ($km{\cdot}h^{-1}$)	Speed ($km{\cdot}h^{-1}$)	Speed ($km{\cdot}h^{-1}$) (% of Vmax*)	Speed ($km{\cdot}h^{-1}$)
Stationary	0 - 1		0.0 - 1.8	0 – 1 $km{\cdot}h^{-1}$	0 - 1.8
Walking	1 - 7	0 – 6	1.8 - 6.1	< 20% Vmax	1.9 - 6.12
Jogging	7 - 12	6 – 12	6.1 - 13.0	20% – 50% Vmax	
Cruising		12– 14			
Striding	12 - 21	14 – 18		51% – 80% Vmax	
Low Intensity Running					6.13 - 12.96
Medium Intensity Running			13.0 - 18. 0		12.97 - 18
High Intensity Running		18 – 20	18.0 - 24.1		18.1 - 24.12
Sprinting	> 21	> 20	24 – 36	81% - 95% Vmax	
Maximum Sprinting				96% - 100% Vmax	> 24.12

* Where Vmax equals individual maximal running speed obtained from match play analysis. It is noteworthy that some boundaries (as published) overlap.

2.7 The Use of GPS in Team Sports

Notwithstanding its limitations, GPS enable objective analysis of player movement patterns and physical demands. Therefore, its recent approval to be worn in competitive play across a number of sports (AFL, hockey, rugby league, rugby union) has seen an increase in research activity among applied sports scientists who are predominantly interested in identifying the locomotive and contact elements of match play. To-date, the AFL has used GPS devices most extensively as it has been allowed within the sport since 2005, but in rugby league and rugby union this has only been possible since 2009 and 2010, respectively (IRB, 2010). For the purpose of this review, only the measured physical demands of rugby union will be discussed.

2.7.1 GPS in Rugby Union

Considering the recent introduction of GPS in competition, relatively few investigations exist at the elite level. Indeed, the literature is primarily based on case studies with very small sample sizes, mainly focusing on the forward and back positions and little attention placed on individual positions. To the author's knowledge only five investigations have previously reported information on the physical demands of the game at the elite level using GPS technology, two of which focused on two players (Coughlan et al., 2011; Cunniffe et al., 2009), the third on eight players (Reid et al., 2013), all of which however, were based on just one match from either a domestic league (Coughlan et al., 2011; Cunniffe et al., 2009) or an international match (Reid et al., 2013) and the fourth on fourteen Spanish international players over 3 matches (Suarez-Arrones et al., 2012). Although recently a more comprehensive analysis of the game has been conducted on 33 players, from thirteen matches (Jones et al., 2015), it was based on players competing in the Celtic and European Cup leagues. Additionally, researchers have utilised GPS technology to investigate U19s and adolescent match demands (Hartwig, et al., 2011; Venter et al., 2011), and the match to match variability of players competing in the English Championship league (McLaren et al., 2015).

As with TMA studies several movement variables have been selected to help create movement profiles of rugby union players. These include: match duration, total distances covered, distances travelled at different speeds, distances at high and low intensity, relative distances, peak speeds, total sprint distances, maximum sprint distances, frequency of sprints, duration of sprint efforts, repeated high-intensity bouts, work-to-rest ratios, and frequency of mild, moderate, high accelerations. Distinctively, researchers have started to make use of the accelerometer data available, presenting findings on exertion rate (body load), exertion index (EI; the instantaneous and accumulated demands of exertion), player load and the frequency of contacts and contact severity, irrespective of its known limitations (Tran et al., 2010; Boyd et al., 2011; Gabbett et al., 2010; Jones et al., 2015).

In accordance with the results of TMA investigations, the findings have generally illustrated that backs cover greater distances than forwards, although large disparities in total distances are still evident, with the backs ranging between 7,227 – 6,272 m and the forwards between 6,689 – 4,757 m, depending on position (Coughlan et al., 2011; Cunniffe et al., 2009; Jones et al., 2015; Reid et al., 2013). With the exception of Jones et al. (2015), these values are substantially higher than what has been reported via TMA technology (Austin et al., 2011b; Roberts et al., 2008). Interestingly, Jones et al. (2015) findings were most similar to the data generated via TMA techniques, and given their larger sample size are arguably more representative of elite rugby match demands than the other small-scale GPS-related studies (Coughlan et al., 2011; Cunniffe et al., 2009; Reid et al., 2013). Alternatively (or in part), the differences might be accounted for by a lower total time spent on the pitch by some players, as Jones et al. (2015) included data on players with a minimum time of 60 minutes (yielding smaller distances covered for such players). Accordingly, when analysed relatively, some of these discrepancies between positions were reduced, with the backs typically covering between 65 and 72 m·min^{-1} and the forwards between 60 – 70 m·min^{-1} (Coughlan et al., 2011; Cunniffe et al., 2009; Jones et al., 2015; Reid et al., 2013). Venter et al. (2011) reported considerably lower distances were covered by U19s rugby union players (4,470 m), and contrastingly found front row forward positions covered the greatest distances (4,672 m) and the back row the least (4,302 m). Yet, this could reflect the standard of play as the duration of a match was only 70 minutes. Furthermore the greater distances covered by the forwards could either be indicative of playing style as only one team was analysed by Venter et al. (2011), or it could exemplify the differences between senior and junior standard demands. Indeed, Hartwig et al. (2011) reported the typical distance covered by adolescence boys was lower than that reported for senior players.

In keeping with the TMA studies, researchers have commonly categorised movement patterns into standing, walking, jogging, striding/cruising and sprinting and likewise found the game to be predominantly played at a 'low' intensity. Cunniffe et al. (2009) identified 89% of total distances were covered at low intensity; 5% in high intensity running (320 m) and 6% sprinting (420 m) when combining forward and back positions. These figures were supported by Jones et al. (2015) who reported low intensity movement accounted for between 90-96% of total distance across the tight forwards, loose forwards, half backs, inside backs and outside backs positional groups. Coughlan et al. (2011), however, found only 75% of the total distances were covered at low running speeds, which is not too dissimilar to the findings of Austin et al. (2011b) who also reported a greater proportion of the game was played at higher intensities Considering Coughlan et al. (2011) investigated elite players competing at the international standard, this might account for higher playing demands, as shown previously in other codes of sports (Gabbett, 2013b; Mohr et al., 2003). Yet, the small sample size used by Coughlan et al. (2011), and indeed Cunniffe et al. (2009), could be the source of such variations, that is, the data epitomise individual performances as opposed to positional demands. Alternatively, the differences could be indicative of the varied speed zone classifications for high intensity running and sprinting applied across the studies. Comparable findings were portrayed across all ages and competitions, with Venter et al. (2011) observing that U19s outside backs and front row forwards typically spent 81% and 64% of the game standing and walking respectively and adolescent boys 80% either stationary or walking (Hartwig et al., 2011). Moreover, McLaren et al. (2015) additionally reported all players to spend on average 82% of match play at low running speeds, when investigating the English Championship league. The greater distances of the backs were attributed to greater walking distances (~ 400 m) than the forwards (Cunniffe et al., 2009) with the full back reported to spend as much as 72 minutes in slower speeds zones (Reid et al., 2013). In support of this Jones and colleagues (2015) found the full back to cover the greatest absolute (3,032 ± 536 m) and relative (32.8 ± 4.0 m) distances walking. Equally, Coughlan et al. (2011) found the forwards covered a greater percentage of total distance whilst jogging and in medium intensity running (59.7%) than the backs (53.2%) and Venter et al. (2011) highlighted the U19 front row forwards spent a considerably greater proportion of time jogging than the outside backs (26.1 ± 3.8% versus 15.6 ± 2.3%, respectively) and more so than any other positional group (similar to the TMA findings). Nonetheless, the backs were still found to attain higher peak speeds than the forward positions ranging from 23 $km \cdot h^{-1}$ - 33 $km \cdot h^{-1}$ and between 21.1 $km \cdot h^{-1}$ - 28.4 $km \cdot h^{-1}$ for the forward positions (Coughlan et al., 2011; Cunniffe et al., 2009; Jones et al., 2015; Reid et al., 2013; Venter et al., 2011).

Moreover, analysis via GPS technology has suggested the backs typically sprint more frequently and for longer durations than the forwards, although precisely how much and how far has varied (Coughlan et al., 2011; Cunniffe et al., 2009; Jones et al., 2015; Reid et al., 2013). For example Reid et al. (2013) reported the lock (forward) did not perform any sprints during matches with the wing position the most (17), whereas Cunniffe et al. (2009) found the forward position to sprint 19 times and back position 34 times during a match. Jones et al. (2015) observed the greatest frequency of sprints was performed by the inside and outside back positions (averaging 20 per match), and the least by the tight forward positions (typically 4 per match - somewhat lower than Cunniffe et al., 2009). Whilst the selection of sprint categories could cause such discrepancies, in that Coughlan et al. (2011) used > 24.1 $km \cdot h^{-1}$ and Reid et al. (2013) used > 24.5 $km \cdot h^{-1}$, both Cunniffe et al. (2009) and Jones et al. (2015) selected the same sprinting speed as > 20 $km \cdot h^{-1}$ and yet still large differences in the number of sprints were evident. McLaren et al. (2015) recently determined high intensity locomotive activity is highly variable from match to match, particularly in back positions, and therefore as Cunniffe et al., (2009) only investigated one match and two players, these discrepancies could be due to variability of the particular match analysed.

Whilst sprint duration, distance and frequency are of interest, players' ability to sprint repeatedly and perform numerous high intensity activity bouts are believed to be crucial to team sports (Austin et al., 2011a; Gabbett, 2012; Roberts et al., 2008; Spencer et al., 2004) as they often occur at critical times during matches. Therefore, a player's inability to perform repeated sprints could be detrimental to the outcome of the game (Austin et al., 2011a; Gabbett, 2012). Repeated sprint ability is widely based on a player completing three or more sprints with less than twenty-one seconds of recovery between each sprint (Spencer et al., 2004). Although in contact sports determining repeated high intensity efforts (RHIE), inclusive of contact elements has been deemed most important (Gabbett et al., 2012), so far few researchers have investigated such activities using GPS devices, with relatively large discrepancies evident in the findings. Jones et al. (2015) reported the loose forward positions were involved in the greatest number of RHIE during match play, averaging 13 per match, whereas McLaren et al. (2015) reported double that number, with the forwards to be involved on average in ~ 26 RHIE, and surprisingly the backs in more with ~ 28 per match. However, McLaren et al. (2015) identified RHIE had one of the highest between-match variations reporting CVs as large as 32% - 62% and thus numerous repeated measures were required in order to ensure a true representation of match demands were presented. Moreover, the standards of players investigated by McLaren et al. (2015) were lower than Jones et al. (2015), which could have caused these differences.

For training purposes the durations of repeated high intensity activity bouts have also been of interest to researchers in gaining a greater understanding of the amount of time players are involved in intense activity. Cunniffe et al. (2009) reported the longest duration of continuous play was seven seconds, which is substantially shorter than the TMA findings (Austin et al., 2011b; Eaton and George, 2006, Roberts et al., 2008) although it was acknowledged that this lower duration was because only locomotive activity was incorporated, excluding any non-locomotive high intensity activity, and therefore arguably is was not a typical representation of repeated high intensity activity bout durations in rugby union.

Whilst match demands have typically been investigated through the analysis of locomotive movement patterns, recently authors have begun to try and identify additional or alternative methods to gain a greater understanding of the demands placed on the body during competition. Whereas characteristically movement demands have been assessed through monitoring distances travelled (based on constant running speeds) and durations spent at different running speeds, little regard has been given to the acceleration and deceleration phases in movements. Although within rugby union some authors have presented descriptors of the frequency of accelerations and decelerations (Coughlan et al., 2011; Cunniffe et al., 2009; Lacome et al., 2014), to-date none have sought to utilise acceleration and deceleration data to determine the high energetic costs that they place on the body. It is thought that the metabolic demand of rapid accelerations on the body is high, even more so than sustained when moving at constant speed (Osgnach, Poser, Bernardini, Rinaldo & di Prampero, 2010), as it requires a superior neural activation to the working muscles (Mero, Komi, Rusko & Hirvonen, 1987). However, as high accelerations do not necessarily always result in reaching the high speed running threshold, the energy used in performing such efforts can often be missed and not accounted for (Akenhead, Hayes, Thompson & French, 2013; Varley & Aughey, 2013). Consequently, in order to try and incorporate such demands a new approach has recently been adopted from the methods outlined by di Prampero, Fusi Sepulcri, Morin, Belli and Antonutto (2005) when partaking in intermittent team sports such as soccer, rugby league and AFL (Coutts, Kempton, Sullivan, Bilsborough, Cordy & Rampinini, 2015; Gaudino, Iaia, Alberti, Strudwick, Atkinson, & Gregson 2013; Kempton, Sirotic, Rampinini & Coutts, 2015; Osgnach et al., 2010).

di Prampero et al. (2005) devised a theoretical model which assumed accelerated running was metabolically equal to inclined running at a constant speed and thus could provide an instantaneous estimate of energy cost when accelerating. The method assumed the incline of the slope mirrored that of the forward accelerations (di Prampero et al., 2005). It was further adapted by Osgnach et al. (2010) to enable its use within team sports and proposed a correction factor should be applied to account for the increased energy cost of moving on grass compared to a treadmill. Utilising the new method has allowed researchers to estimate distance, speed, accelerations, energy expenditure, metabolic power, equivalent distance, equivalent distance index and anaerobic index, in addition to making comparison with the more traditional approaches (Coutts et al., 2015; Kempton et al., 2015; Osgnach et al., 2010). Interestingly, by applying such methods to assess rugby league, the more traditional techniques were identified to underestimate the physical demands, particularly in determining distances covered at high running speeds (> 14.4 $km \cdot h^{-1}$) when compared to distance determined above high power threshold (> 20 W/kg), albeit position-dependant (Kempton et al., 2015). It was speculated that traditional findings could underestimate distances by 76% - 37% for hit-up forwards and outside backs respectively. The greatest differences were evident in positions that typically occupied the central field locations. It was conceivable that whilst such positions frequently accelerated, often their efforts did not result into what was classified as a high speed running effort, probably as such positions were confined by limited space due to how the opposition typically lined up in front of them. This was similar to soccer where it was reported that elite players characteristically spent 18% of total distance at high running speeds, yet spent more than 42% of total energy expenditure at high power output (> 20 $W \cdot kg^{-1}$) which has previously been identified to be an equivalent to high speed running (> 14.4 $km \cdot h^{-1}$) (Osgnach et al., 2010). Researchers therefore proposed this was a useful alternative method to assess intermittent team sports, either on its own or to accompany the traditional methods (Kempton et al., 2015; Osgnach et al., 2010).

However, in contrast, when applying the new method to examine the physical demands of the AFL, Coutts and colleagues (2015) reported the newer technique underestimated total distances and was not an appropriate method for analysis. This was attributed to the differing demands of the AFL in that players are less confined by space and it being more likely that high accelerations lead to high speed running efforts. However, whilst its usefulness in team sports has been noted, there are a number of flaws with the method that should be considered. Importantly, it is still unable to account for the contact and static exertions elements of rugby union, which is pivotal in providing a comprehensive analysis of the game. What is more, it relies heavily on the ability of GPS devises to report the frequency of accelerations and decelerations accurately. While recent development in GPS technology (10 Hz and 15 Hz devices) have seen an increase in the accuracy of GPS in detecting accelerations (Boyd et al., 2011; Gabbett et al., 2010) its accuracy when capturing at 5 Hz and 1 Hz has been questioned (Buchheit, Haddad, Simpson, Palazzi, Bourdon, Di Salvo & Mendez-Villanueva, 2013;

Varley, Fairweather & Aughey, 2012). Moreover, few investigations have been carried out to test the validity and reliability of the method itself (Coutts et al., 2015). Whilst the method was said to equate distances covered above ~14.4 $km \cdot h^{-1}$ to high power efforts of 20 $W \cdot kg^{-1}$ (Osgnach et al., 2010), the analysis was based on the correlation coefficient, which has previously been illustrated not to be the best measure of reliability (Bland & Altman, 1986). Moreover, the use of 14.4 $km \cdot h^{-1}$ to signify high intensity movement is again based on an arbitrary and absolute value, which has been challenged. Therefore, although this method potentially provides a further understanding of the demands of match play in team sports, currently it is best served as an additional form of analysis in conjunction with the more traditional approach. Moreover, researchers have begun to use the integrated accelerometers within GPS devices to identify body loads, frequency and severity of contacts sustained during match play to help gain a further understanding of match demands (Boyd et al., 2011; Coughlan et al., 2011; Cunniffe et al., 2009; Gabbett et al., 2010; Jones et al., 2015; McLaren et al., 2015; Venter et al., 2011).

The methodologies employed have, in the main, been dependant on the model of GPS devices used. Investigations utilising GPSports devices to determine contact elements have typically used the predetermined impact "G" forces zones, recommended by manufacturers to identify different severities of contacts throughout match play (Table 2.15) (Coughlan et al., 2011; Cunniffe et al., 2009; Venter et al., 2011). Yet, as with movement classifications, some controversy surrounds the selection of impact classifications as absolute figures have been used across all positions with little evidence on the validity and reliability of the impact zones in measuring what they claim to. Surprisingly it appears that all researchers so far have simply adopted the in-built impact classifications without questioning it. McLellan et al. (2011a) used the impact zone classifications to analyse player exposure to contacts within the game of rugby league. Video based analysis was also used to identify the average frequency of tackles (defined as an "event that halted the progress of an opponent in possession of the ball" p. 1557) and hit-ups (defined as "a player being tackled in possession of the ball during match play" p. 1557) during match play. The findings highlighted a cause for concern was that the average total contacts reported for all positions via the GPS device was 830 ± 135 compared to 14.9 ± 10.5 and 10.2 ± 3.8 (totalling ~25.1) for the average number of tackles and hit-ups, respectively, identified from the video footage. Interestingly, even with the exclusion of zones 1 and 2 (zones which were suggested to record changes in direction of movement and contacts with the ground) the total number of contacts identified by the GPS was still substantially greater (~465 contacts) than determined via the video analysis. Such findings would imply large errors occur in determining the frequency of contacts during match play when using GPSports SPI Pro units and thus the raw data exported from such devices are unable to detect the frequency of contacts accurately. Therefore, the data from the in-built accelerometer of the GPSsports SPI Pro device has to be treated with scepticism, even though some authors have still proceeded to utilise it.

Table 2.15 Zone impact classification described by Cunniffe et al. (2009), Coughlan et al. (2011), Venter et al. (2011), McLellan et al. (2011a; 2011b), McLellan and Lovell (2012).

Zone	Impact Force (Gravitational 'G' force)	Collision Classification
1	< 5.0 – 6.0	Very light impact, hard acceleration/deceleration/change of direction while running
2	6.1 – 6.5	Light to moderate impact, minor collision with opposition player, contact with the ground
3	6.5 – 7.0	Moderate to heavy impact, making tackle or being tackled at moderate velocity
4	7.1 – 8.0	Heavy impact, high-intensity collision with opposition players/s, making direct front on tackle on opponent travelling at moderate velocity, being tackled by multiple opposition players when running at sub-maximum velocity
5	8.1– 10.0	Very heavy impact, high-intensity collision with opposition player/s, making direct front on tackle on opponent travelling at high velocity, being tackled by multiple opposition players when running at near maximum velocity
6	>10.1	Severe impact, high intensity collision with opposition player/s, making direct front on tackle on opponent travelling at high velocity, being tackled by multiple opposition players when running at maximum velocity

*It is noteworthy that some boundaries (as published) overlap.

Such studies in rugby union have portrayed the forwards as being characteristically involved in a greater total number of impacts, on average ~ 300 – 400 more than the backs (Coughlan et al., 2011; Cunniffe et al., 2009). However, Cunniffe et al. (2009) noted a higher total frequency than Coughlan and colleagues (2011) for forwards and backs (1,274 versus 838 and 798 versus 573 respectively), but between-study similarities were evident for the forward positions for the number of 'very heavy' (8-10 G) and 'severe' (10^+ G) impacts made, with Cunniffe et al. (2009) reporting 56 and 13, and Coughlan et al. (2011) 53 and 10, respectively. However, backs have demonstrated, large variations, Cunniffe et al. (2009) reported a total of 24 very heavy collisions and 4 severe, in comparison to 40 and 13, respectively, determined by Coughlan et al. (2011). These disparities could be representative of different playing positions within the backs, as the data of Cunniffe et al. (2009) was based only on one fly half and Coughlan et al. (2011) on one centre. Further inconsistencies were evident with Cunniffe et al. (2009) illustrating the forward was involved in more than double very heavy impacts (56 versus 24) and severe impacts (13 versus 4) in comparison to the back, respectively, whereas Coughlan and colleagues (2011) reported that although the forward was involved in a greater number of very heavy impacts compared to the back (53 versus 40), the back suffered more severe impacts (13 versus 10). It was proposed that this could be expected considering the greater peak running speeds attained by the backs (Venter et al., 2011) and hence the greater force when collisions occurred. Moreover, the larger involvement in very heavy impacts by the forwards could be owing to the number of rucks, scrums and lineouts they participate in (Quarrie et al., 2013). Interestingly, Coughlan et al. (2011), through the use of video footage, determined the forward made 10 tackles and the back 12, which was not too dissimilar to the number of total impacts in the severe impact zones (10 and 13), perhaps providing some evidence that tackles could be correlated with severe impacts. However, 90% of the tackles were high tackles occurring between the shoulder and mid-thoracic area, though this could just be due to the circumstances of the match. Indeed, even though both Cunniffe et al. (2009) and Coughlan et al. (2011) have presented the findings of the contact elements from accelerometer data (produced by the 1 Hz and 5 Hz GPSport devices) their validity is highly questionable and should be interpreted accordingly.

Evidently, the current literature has utilised GPS to provide a more comprehensive analysis of the contemporary game than ever before. Whilst there now exists information on the locomotive movement analysis, including absolute and relative distances, the frequency, duration and distances completed when sprinting and performing repeated high intensity exercise bouts, across elite, sub elite and junior levels, the depth is limited. With the exception of Jones et al. (2015), there is paucity in the number of participants investigated and these results typically represent individual playing efforts rather than the general positional information on the physical demands of elite rugby union. Accordingly, analysis of one match and one player per position is not sufficient to provide a convincing, contemporary analysis of the elite game and therefore further investigation is warranted. Moreover, to-date few studies have investigated both the locomotive movement patterns of individual positions and their performance-related involvement of match play (particularly in reference to individual positions) based on the same data set, which is surprising since the game encompasses both elements

2.8 The Assessment of Performance Indicators

Performance indicators are “a selection or combination of action variables that aim to define some or all aspects of a performance” (Hughes & Bartlett, 2002, p. 739). Generally they are used to describe performances against outcome, or in comparison to opposition or other athletes, although often used on their own to determine the performance of a team and/or individual (Hughes et al., 2012). Performance indicator data has typically been presented in a number of ways, including frequencies (Eaves & Hughes, 2003; Hughes & White, 1997; Ortega et al., 2009; Potter, 1997; Stanhope & Hughes, 1997; van Rooyen et al., 2006; Lim et al., 2011), percentages (James et al., 2005; Jones et al., 2004; Jones et al., 2008) and ratios (Hughes & Bartlett, 2002), making interpretations and comparisons between studies difficult. Often only one method has been selected by an author causing the potential loss of data and incorrect conclusions to be drawn (Hughes & Bartlett, 2002). Whilst the need for the inclusion of the frequencies was acknowledged by Hughes and Bartlett (2002), it was also proposed it was essential that authors referenced the frequencies in relation to time to allow data to be presented in a dimensionless form and reduce the risk of incorrect conclusions being made.

2.8.1 Selection of Performance Indicators in Rugby Union

The analysis of closed skills in individual sports, where technique is crucial for success, is often determined through the use of hierarchical technique models (Hughes & Bartlett, 2002), which incorporate proven performance parameters that are linked with outcomes (Hay & Reid, 1988). The selection of the key performance indicators (often referred to as 'KPIs') within team sports, particularly rugby union, is characteristically subjective in nature, leading to an array of different KPIs being analysed across numerous investigations. Researchers have utilised statistics produced by the governing body (International Rugby Board, IRB) or "official websites" (Ortega et al., 2009; van Rooyen et al., 2006; Vaz et al., 2011), to guide their choices of KPIs, or selected indicators that a team is perceived to be lacking relative to their more successful counterparts (Prim et al., 2006). Few however, have attempted to establish the critical performance indicators for rugby union through research (Hughes et al., 2012; James et al., 2005; Jones et al., 2004, Jones et al., 2008; Lim et al., 2009; Lim et al., 2011), and surprisingly attempts to depict specific KPI profiles for individual positions are relatively scarce.

One of the most objective approaches in determining general rugby union team performance KPIs and more specific, individual position KPIs was adopted by Jones et al. (2004) and James et al. (2005). A list of behaviours were created by three performance analysts (with over 40 years of combined experience in rugby union) which was considered and refined by a panel of coaching staff (with a combination of playing and coaching experience at the elite level for 50 years) to derive the common and specific KPIs listed in Tables 2.16 and 2.17. The selection of performance indicators were deemed adequately reliable (error of < 5%) and although the team performance indicators were unable to distinguish clearly between winning and losing outcomes, higher success percentages in winning performances were evident in selected KPIs.

Yet, variations in the selection of the KPIs used in rugby union research continue to prevail. For example, when investigating the changes in patterns of play, Eaves, Hughes and Lamb (2005) proposed varying key game actions (as described in Table 2.18). Similarly, Lim and colleagues (2009) collaborated with team coaches to identify the KPIs (Table 2.19). However, Lim et al. (2009) weighted each in relation to its relative importance to the game's outcome and scored each with either a positive or negative value (ranging between +75 to -75), yielding a total net game performance (NGP) post-match. Following analysis of 39 matches over three seasons, Lim et al. (2009) reported moderate to strong correlations between the NGP and the score margin, suggesting the matrix was capable of predicting the probability of winning.

Table 2.16 Team performance indicators described by Jones et al. (2004).

Team Performance Indicators			
1	Scrum Success (analysed team)	12	Breaks made as a % of the total analysed team carries
2	Scrum Success (opposition ball)	13	Turnovers won as a % of the total turnovers made by both teams
3	Lineout Success (analysed team)	14	Place kick success
4	Lineout Success (opposition ball)	15	Tries scored as a % of the total tries scored in a game
5	Ruck Success (analysed team)	16	Penalties conceded as a % of the total penalties awarded in a game
6	Ruck Success (opposition ball)	17	Errors made in area 1 (defensive third) as a % of total errors made by the analysed
7	Maul Success (analysed team)	18	Errors made in area 2 (middle third) as a % of total errors made by the analysed
8	Maul Success (opposition ball)	19	Errors made in area 3 (attacking third) as a % of total errors made by the analysed
9	Successful tackles made as a % of the total number of analysed team tackles	20	Total frequency of errors made in a game
10	Offload tackles made as a % of the total analysed team tackles	21	Frequency of intrusions in area 3 (attacking third)
11	Offloaded passes made as a % of the total analysed team carries	22	Time in possession (minutes)

Table 2.17 Performance indicators outlined in James et al. (2005).

Positions	Indicators
Props	Successful/Unsuccessful - Tackles/Ball carries/Passes. Tries Scored/Penalties conceded/Handling errors
Hooker	Successful/Unsuccessful - Tackles/Ball carries/Passes. Tries Scored/Penalties conceded/Handling errors. Lineout Throw
Locks	Successful/Unsuccessful - Tackles/Ball carries/Passes. Tries Scored/Penalties conceded/Handling errors. Successful/Unsuccessful Lineout Takes Successful/Unsuccessful Restarts
Back Row	Successful/Unsuccessful - Tackles/Ball carries/Passes. Tries Scored/Penalties conceded/Handling errors. Turnovers Won
Scrum Half & Outside Half	Successful/Unsuccessful - Tackles/Ball carries/Passes. Tries Scored/Penalties conceded/Handling errors. Successful/Unsuccessful Kicks
Wings & Full Backs	Successful/Unsuccessful - Tackles/Ball carries/Passes. Tries Scored/Penalties conceded/Handling errors. Successful/Unsuccessful Kicks Successful/Unsuccessful High Ball Takes

Table 2.18 Key game action (KPIs) variables in rugby union (from Eaves, Hughes & Lamb, 2005, p 61).

Game Action	Operational Definitions
Pass from the dummy or scrum half position	The first pass made by any player after completion of ruck, maul, scrum or lineout
Pass in open play	A pass made by any player excluding, offloads, passes from dummy/scrum half or the initial pass from a penalty or free kick
Offload	A pass made when the ball carrier is in the process of being tackled
Phase activity end	A period of play which exists between subsequent rucks. Phase activity also ends when the ball is called dead and recommences with the subsequent reintroduction of the ball into play
Set possession	A continuous possession period for either team. Set possession is ended when the possession is passed over to the opposition
Kick in play	A kick in open play which does not go into touch either by intention or error
Kick out of play	A kick in open play which leaves the field of play and results in a set piece restart (excludes kicks from a penalty)
Ruck	(Law 16, p.92) - 'A phase of play where one or more players from each team are in physical contact on their feet close around the ball in contact with the ground.' The ruck is deemed to end when the ball leaves the ruck
Maul	(Law 17, p.97) - 'A maul occurs when a ball-carrier is held up by one or more opponents and one or more of the ball carrier's team mates bind onto the ball-carrier.'
Scrum	(Law 20, p.123) - Formed in the field of play when eight players from each team, bound together in three rows for each team, close up with their opponents so that the heads of the front rows are interlocked
Lineout	Law 19, p.113) - A restart to play after the ball has gone into touch, with a throw in between two lines of players

Table 2.19 Individual game actions, operational definitions and weightings (Lim et al., 2009).

Individual Game Actions	Operational Definition	Weighting
Try Scored	5 points awarded to the scoring team when the ball is placed down in the try area	(+) 75
Try Conversion	Additional 2 points awarded when the ball is kicked between the posts after a try is scored	(+) 30
Penalty Conversion	3 points awarded when the ball is kicked between the posts from a penalty	(+) 45
Drop Goal	3 points awarded when the ball is drop kicked between the posts from open play	(+) 45
Tactical Kick Regained	Team regains possession after a tactical kick	(+) 6
Breach	Carrying the ball through the opposition defensive line resulting in at least one opposition player having to turn around to make the tackle	(+) 6
Field Kick > 40 m	Successfully kicking the ball over a distance of 40 m or more	(+) 3
Offload	Passing the ball on to a supporting player when being tackled, thus maintaining the forward flow of play	(+) 6
Ball Placement (Fast)	Quick placement (<3s) of ball when tackled, making the ball available for quick recycling	(+) 3
Attack Support	First supporting player to arrive in a tackle situation to lend attacking support	(+) 3
Set Piece (Score)	5 points awarded to the scoring team when the ball is placed down in the try area directly off a set piece play (i.e. scrum or line out)	(+) 3
Ball Carry	Carrying the ball into the opposition defensive line causing more than one opposition players to commit to a tackle situation	(+) 2
Pass/catch (Under Pressure)	Passing/catching the ball under opposition pressure. Includes picking the ball from base of ruck.	(+) 2
Field Kick (Under Pressure)	Successfully kicking the ball under opposition pressure	(+) 2
Ball Placement (Medium)	Medium speed (3-5s) placement of ball when tackled, allowing for average recycling of the ball	(+) 2
First Arrival (Ruck)	First player to arrive in a tackle situation to clear out the ruck	(+) 2

Individual Game Actions	Operational Definition	Weighting
Second Arrival	Second player to arrive and secure the ruck	(+) 2
Set Piece (Good Platform)	Set piece won, unless driven backwards	(+) 2
Ball Carry (No Fight)	Carrying the ball into the opposition defensive line requiring only one opposition player to commit to the tackle situation	(+) 1
Pass/catch (No Pressure)	Passing/catching the ball under no opposition pressure	(+) 1
Field Kick (No Pressure)	Successfully kicking the ball under no opposition pressure	(+) 1
Ball Placement (Slow)	Slow placement (>5s) of ball when tackled, causing slow recycling of the ball	(+) 1
Third and Fourth Arrival	Third and fourth players to arrive to the ruck +1	(+) 1
Set Piece (Untidy)	Set piece won, but driven backwards or wheeled to disadvantage	(+) 1
Try Saving Tackle	A tackle that directly results in preventing a certain try from being scored by the opposition	(+) 25
Kick Receipt (Contested)	Receiving a kick under a contested situation	(+) 3
Turnover Tackle	A tackle that results in turnover of possession	(+) 10
Set Piece Turnover	Turnover of possession from a set piece situation	(+) 2
Dominant Tackle	Tackle that drives opposition player backwards	(+) 2
Jackal	Attempt to steal the ball from a tackle situation in a turnover attempt	(+) 2
Set Piece (Disrupt)	Driving the opposition set piece backwards or wheeling them into a disadvantageous situation	(+) 1
Kick Receipt (No Pressure)	Receiving a kick under no pressure	(+) 1
Passive Tackle	Tackling of opposition player	(+) 1
Tackle Assist	Assisting in a tackle situation	(+) 1
Set Piece (Opposition Platform)	Engaging in set piece but still allowing the opposition to have a good platform to attack from	0

Individual Game Actions	Operational Definition	Weighting
Error in play	Errors made in play (e.g. handling errors etc)	(-) 2
Game Law Infringement	Infringement of the laws of the game resulting in free kick or penalty	(-)10
Turnover Event	Error in play that directly results in turnover of possession to the opposition	(-)10
Game Law Infringement	Infringement of the laws of the game resulting in free kick or penalty	(-)10
Set Piece Lost/Infringement	Lost own set piece or infringement of set piece rules	(-) 2
Turnover Event	Error in play that directly results in turnover of possession to the opposition	(-)10
Missed tackle Set Piece Lost/Infringement	Missing a tackle Lost own set piece or infringement of set piece rules	(-) 6 (-) 2
Set Piece Opposition Score Missed tackle	Opposition score from a set piece Missing a tackle	(-) 3 (-) 6
Yellow Card Set Piece	Results in carded playing being sent off to the sin bin for 10 minutes, leaving their team one player down for that duration	(-) 45
Opposition Score	Opposition score from a set piece	(-) 3
Yellow Card	Results in carded playing being sent off to the sin bin for 10 minutes, leaving their team one player down for that duration	(-) 45
Red Card	Results in carded player being sent off, having no further participation in the game, leaving their team one player down for the rest of the game	(-) 75

Clearly, as numerous performance indicators have been used in an attempt to identify the 'crucial' or 'key' indicators, it is difficult to consolidate the findings. Such disparities could be owing to the specific areas of importance and dominance for particular teams or individuals and therefore the use of one generic template across all research has not been feasible. Indeed, the recent work of Hughes et al. (2012) illustrated that whilst simplistic performance analyses can provide informative data, the data requires ‘meaning’ for it to be useful. Nonetheless, using the various KPIs identified researchers have endeavoured to distinguish performance aspects of match play irrespective of the era, success or position. However, whilst most authors aim to provide useful information on performance elements of match play, few have considered the variable nature of match play and its effect on the stabilisation of performance indicators.

Characteristically sports performances of individual players and or teams can be very variable in nature (McLaren et al., 2015) and are often influenced by a number of external factors, including opposition (Gabbett, 2013b), scoreline (Lago-Peñas, 2012; Vaz et al., 2011), venue (Devlin, Brennan & O’Donoghue, 2004), time of the season and competition (Lago-Peñas, 2012). As a result, examining the frequency of performance indicators from one match to another can differ enormously and therefore determining which match is most representative of the ‘norm’ can prove difficult (O’Donoghue, 2005). Consequently, Hughes and Bartlett (2002) proposed researchers must make certain the data has stabilised prior to reporting it, to ensure a normative data set can be conveyed.

However, when data is presented in performance analysis investigations, it is often assumed that the data provided (whether it be on an individual, team or competition basis) has stabilised and a normative profile has been achieved (Hughes, Evans & Wells, 2001). Hence it is therefore presumed that the information is representative of the population. Yet, this is often not the case, as many researchers omit to notate the number of matches required to ensure a stable profile has been attained, thus questioning the accuracy of the findings in such cases (Hughes et al., 2001). Whilst some authors argue that the larger the database of information the more stable, accurate and representative the profiles of teams, positions and players will become (Potter & Hughes, 1999). Others debate if the database of information is too large, important information and trends in the data can be lost due to a lack of sensitivity (Hughes & Bartlett, 2002).

Within rugby union investigations, few researchers have sought to identify the number of matches required to produce a ‘normal’ profile of match demands (Eaves & Hughes, 2003; Eaves, Hughes & Lamb, 2005; James et al., 2005; Marshall & Hughes, 2001; Parsons et al., 2001; Vivian, Mullen & Hughes 2001). For the most part, researchers assume stabilisation has occurred, irrespective of the number of matches analysed and present the findings regardless. Across the literature there appears to be three most frequently used methods, which have been outlined by Hughes et al. (2001), James et al. (2005) and O’Donoghue, (2005). Hughes et al. (2001) analysed a number of matches to determine a typical value for a performance indicator and identify whether that sample provided a stable representation of the data. Cumulative mean values for performance indicators across a specified number of matches were calculated. It was determined that the cumulative mean stabilised once it fell within predetermined suitable error limits, agreed as 10%, 5% or 1%. At this point the variable was classified as stable and the number of matches this required was noted and utilised as a minimum standard to enable a normative profile. However, O’Donoghue (2005) criticised the method on the basis that as the limits of error link the cumulative mean with the final mean of all matches, there was a danger of a substantial difference being overlooked and deemed acceptable. Moreover, O’Donoghue (2005) argued that the application of the method may be limited, as inevitably some performance indicators are erratic in nature and therefore may have difficulty in stabilising. James et al. (2005) second the concerns of O’Donoghue (2005) in agreeing that difficulties could arise with the stabilisation of certain performance indicators and additionally that the method could be inhibited in certain instances due to varying team factors. Consequently, both O’Donoghue (2005) and James et al. (2005) proposed alternative methods.

O’Donoghue (2005) suggested a three-stage method should be used once a large dataset of performance indicators had been established. O’Donoghue (2005) proposed, firstly to identify a ‘normative performance percentile’ (p. 107) for all performance indicators that are of interest; secondly, to utilise information from several matches on individual subjects, to identify mean and standard deviation for each individual performance indicators; thirdly, to identify on a radar chart and relate individual subject’s information to the normative data whilst using upper and lower quartiles to denote the spread of performances (p. 107). O’Donoghue (2005) claimed employment of these methods provided distinct advantages over the proposed technique of Hughes et al. (2001), namely that a single table/chart could be used to identify the number of matches required to ensure a stable data set, compared to separate charts per individual indicators when applying the techniques of Hughes et al. (2001). The inclusion of upper and lower limits is beneficial as it allowed and acknowledged the variability of individual performances within sports. Furthermore, with this method the data is related and compared to normative performance data whereas Hughes et al. (2001) is not. Lastly, this technique has scope to be compared across players and within player performances, unlike the method of Hughes et al. (2001). Whilst the method outlined by O’Donoghue (2005) provides some advantages it is not without its limitations. Mainly, a large data set of performance indicators need to be established initially, which can be a lengthy process in some sports and impossible when collecting data for the first time (James et al., 2005). Secondly, whilst it is compared to normative performance data, it does not take into account the standard of competitors (teams, individuals players or opposition) when creating the normative performance data sets, so potentially may not truly be representative. Contrastingly, James et al. (2005) proposed the use of confidence intervals to “calculate estimates of population medians from the sample data” (p. 67) suggesting upper and lower limits are a better representation as a performance guide, rather than using just a median figure on its own. Unlike the methods portrayed by Hughes et al. (2001) and O’Donoghue

(2005), James et al. (2005) reported performance profiles could be determined by utilising only a small number of data sets instead of requiring an initial large database of information. However, this method did require data to be collected sequentially, which could be difficult particularly when trying to attain data from the elite level. Nonetheless, whilst the three methods provided both individual advantages and disadvantages, all authors agree that it is essential to ensure the data presented for performance indicators have stabilised prior to reporting them, or at a minimum acknowledge this and use previous findings in the literature to determine an acceptable number of games required to be analysed to ensure the stability of normative profiles for different performance indicators.

2.8.2 Amateur versus Professional

Following rugby union's professionalism in 1995, reports of an increase in the incident of injury (Garraway et al., 2000) emerged causing a greater demand for investigation into the extent to which the game had developed from the pre- to post-professional era. Observations determined the professional game was more intense, open and faster-paced, moving away from the maul-dominated game, as an increase in the frequency of rucks, accompanied by a decrease between contact periods was found (Eaves & Hughes, 2003). Moreover, an increase in the ball in play time was found with Eaves and Hughes (2003) detecting a 5.9% increase across eras, and similarly Eaves, Hughes and Lamb (2005) reported an increase of 5 minutes and 49 seconds. Indeed the study of Eaves, Hughes and Lamb (2005) was one of the few to examine the effect playing status had on performance variables and consequently identified a number of substantial differences. A noteworthy 39.6% increase in the number of passes between eras was evident with an 82.8% increase from the scrum half position alone. However, considering the increased ball in play time, this is not surprising. Eaves, Hughes and Lamb (2005) found the frequency of kicks to be reduced by 22.5%, along with a particular reduction in the number of kicks into touch and a concomitant decrease in the average number of lineouts per game from 47 to 31. It was noted though that the changes to the laws of the game during the period of investigation should not be ignored as these equally could have contributed to this difference.

However, whilst literature on performance profiles are available pre- and post-professional era (Parsons & Hughes, 2001; Potter, 1997; Vivian et al., 2001) in the main authors have focused their attention on assessing the game in regards to winning and losing and determined this as the only discernible measure (Carter & Potter, 2001; Hughes & White, 1997; Jones et al., 2004; Lim et al., 2011; Ortega et al., 2009; Prim et al., 2006; Stanhope & Hughes, 1997; van Rooyen et al., 2006; van Rooyen & Noakes, 2006; Vaz et al., 2011). It appears that the consensus among researchers is that scoring more tries (Carter & Potter, 2001; Hughes et al., 2012; Hughes & White, 1997; Jones et al., 2004; Ortega et al., 2009; Prim et al., 2006; Stanhope & Hughes, 1997), having a superior kicking game (Stanhope & Hughes, 1997; Vaz et al., 2011), with a prevailing lineout and dominating the contact area (in tackling, rucking and mauling) (Hughes & White, 1997; Stanhope & Hughes, 1997; van Rooyen et al., 2006) contribute to success in rugby union. Although predominantly researchers have focused on presenting data on KPIs for an entire team (James et al., 2004; Stanhope & Hughes, 1997; van Rooyen et al., 2006; Vaz et al., 2010), typically at the international standard, including World Cups and Five/Six Nations tournaments (albeit employing various methodologies), few studies have identified performance profiles for individual playing positions (Hughes et al., 2012; James et al., 2005; Jones et al., 2015; Quarrie et al., 2013).

2.8.3 Positional Differences

James et al. (2005) and more recently Quarrie et al. (2013) have reported performance profiles per position for northern hemisphere leagues and international games, respectively. Whilst Jones et al. (2015) recently presented information on the movement characteristics of individual positions participating in the Celtic and European Cup leagues, performance variables were not reported on an individual basis. Identifying position-specific information can provide added insight into the demands of the position and hence potentially aid in preparing players for competition. Similar to the KPIs analysed across team performances, a variety of indicators have been analysed yielding both common and contrasting findings.

James et al. (2005) found the flanker and scrum half positions to engage in the most tackles (~ 10 per game) during northern hemisphere domestic league games, albeit lower than recorded for back rowers at the international standard (~ 14 per game; Quarrie et al., 2013). Both James et al. (2005) and Quarrie et al. (2013) reported the lowest frequency of successful tackles were completed by the outside backs and prop positions, yet, again the demand was shown to be greater at the international standard with the outside backs involved in ~ 1 tackle and the props ~ 4 tackles more per game. Interestingly, the flankers and the number 8 positions conceded a greater number of penalties, with both James et al. (2005) and Quarrie et al. (2013) reporting comparable findings of 1 per game on average.

The scrum half position was epitomised by successfully passing the ball a substantially greater number of times than any other position, typically ranging between 45 - 48 passes per game (James et al., 2005; Quarrie et al., 2013). Furthermore, James et al. (2005) found the scrum half to perform the most successful ball carries (9.9) with the locks the least (2). However, no differences were determined in the occurrences of tries scored in the northern hemisphere (James et al., 2005), whilst the centre and the wing positions scored considerably more tries than any other positions (0.18 ± 0.43 and 0.16 ± 0.36, respectively) at international standard (Quarrie et al., 2013).While differences were evident across positions, James and colleagues (2005) found significant disparities within positions when two or more players were investigated. For example, among three props analysed, one was found to carry the ball three times more successfully (6.2 carries) than another (2 carries). Similarly, considerable differences were displayed within the fly half position, particularly when comparing the number of successful ball carries and tackles made. This was in accordance with the findings of McLaren et al. (2015), which highlighted that high intensity aspects of match play, including both locomotive and impact based efforts, did not stabilised easily, causing difficulties in the interpretation of player profiles. Accordingly Jones et al. (2004) and James et al. (2005) proposed that such findings could potentially inhibit the identification of general positional profiles across all teams and would be more pertinent for individual teams or competitions. Likewise, Hughes et al. (2012) also found significant differences were apparent within positions, particularly the outside half (fly half) position. It was noted that whilst identifying general positional profiles were possible, they were more reflective of individual player strengths or weakness (Hughes et al., 2012). However, with the exception of Quarrie et al. (2013), whereby a large database of players and matches were examined, data selection in both James et al. (2005) and Hughes et al., (2012) was small. James et al. (2005) investigated a maximum of eight players per position, and similarly when investigating international players, Hughes et al. (2012) acknowledged their findings were limited due to a relatively small sample size. Moreover, contrary to recommendations by Hughes and Bartlett (2002), James et al. (2005) only used frequency data to present the findings, allowing for some misinterpretation of the data. Therefore, further investigation is required, particularly at the professional club level in attempt to construct positional profiles.

2.9 Match Fluctuations in Team Sports and Rugby Union (Fatigue and Pacing)

Fatigue is an extremely complex condition, which can be affected by central and peripheral factors (Brooks, Fuller, Kemp & Reddin, 2008). By definition, the measurement of fatigue requires a maximal voluntary contraction (Miller, Kent-Braun, Sharma & Weiner, 1995;

Vøllestad, 1997), which is intrusive and logistically difficult to obtain in team sports. Consequently, researchers have proposed that high intensity running (HIR) can be used as an alternative, non-invasive measure that reflects the occurrence of fatigue, as decrements in HIR have previously been associated with an increase in other markers of fatigue (Bansgbo et al., 1991; Krustrup, Mohr, Steensberg, Bencke, Kjaer & Bangsbo, 2006; Mohr et al., 2003; Rampinini et al., 2007b).

A substantial amount of work has been carried out across numerous team sports (primarily soccer), which has provided some information on the extent that fatigue affects players during competition (Carling & Dupont, 2011; Mohr et al., 2003; Mohr, Krustrup & Bangsbo, 2005; Reilly, Drust & Clarke, 2008) when performances are compared to the baseline values (Waldron & Highton, 2014). Researchers have demonstrated decreases in physical efforts and HIR between the first and second halves, in the final stages of games and temporarily following the most intense period of match play across the AFL, rugby league and soccer (Bansgbo et al., 1991; Bradley & Noakes, 2013; Carling & Dupont, 2011; Coutts et al., 2010; Mohr et al., 2003; Rampinini et al., 2007b; Waldron et al., 2013). Additionally, in soccer, authors have reported a reduction in skill-related aspects of performance in the second half (Rampinini, Impellizzeri, Castagna, Coutts & Wisløff, 2009), although others have disagreed (Carling & Dupont, 2011). Coutts et al. (2010) identified a decline in HIR in the final quarter of AFL matches compared to the first and when HIR and acceleration data were normalised, a reduction towards the latter aspects of the game was also evident, suggesting fatigue was manifested in the inability to produce maximal sprint efforts. Likewise, the findings in rugby league have indicated the presence of fatigue towards the concluding parts of matches through the decline in high intensity activity (Sirotic, Coutts, Knowles & Catterick, 2009; Sykes, Twist, Nicholas & Lamb, 2011).

It has been proposed that HIR can reduce by 11.5% in the second half compared to the first (Sirotic et al., 2009), with as much as a 30.5% reduction from the first to fourth quarter in (Sykes et al., 2011) in other team sports. However, across the game of rugby union few researchers have investigated the changes in movement profiles and particularly static exertions over the course of match play to assess if any association with fatigue exists. What is more, of the limited literature available, contrary to other team sports findings, no differences were illustrated in HIR between first and second halves (Coughlan et al., 2011; Cunniffe et al., 2009; Duthie et al., 2006; Jones et al., 2015; Lacome et al., 2014; Roberts et al., 2008). For example, when investigating elite English Premiership players, Roberts et al. (2008) reported a decrement in total distance covered at 50 - 60 minutes (704 ± 51 m) and 70-80 minutes (738 ± 91 m) of match play compared to the first 10 minutes (838 ± 72 m), but no substantial differences in the mean or maximum duration in HIR or static exertions were evident. This concurred with the findings of Jones et al. (2015) who reported no differences in high speed running, RHIE or high accelerations between the first and second halves, although substantial differences in low intensity efforts, particularly at movement speeds of "striding" and "cruising" were present. Whilst few substantial changes were evident across any 10-minute periods in the first half, significant changes were identified in the latter parts of match play (50-60, 60-70, 70-80 minutes) when compared to the first 10 minutes of the second half. Accordingly, the recent investigations using GPS (Coughlan et al., 2011: Cunniffe et al., 2009) revealed similar findings with few differences shown between total distances and distances in high and low running speeds between the first and second halves. However, as the total sample size in both investigations was only 2, no statistical analysis was carried out and hence the findings could most likely reflect the participants' playing styles. However, Lacome et al. (2014) did report a decline in accelerations between the first and second halves (mean acceleration decrease 2.9%) although only significant for the back row positions, and whilst this might be indicative of fatigue, it could be due to an intentional reduction in activity level. Interestingly, both Coughlan et al. (2011) and Cunniffe et al. (2009) found distances or percentages of distances were highest in the second half of match play (although less pronounced for the back positions). Even though not significant, Jones et al. (2015) observed high intensity running, sprint running and relative measures of high speed running were augmented in the final 10 minutes of match play, suggesting rugby union players perhaps make use of pacing strategies as proposed in other team sports (Coutts et al., 2010; Waldron et al., 2013).

Pacing strategies adopted by athletes typically differ with the most common being, negative, all-out, positive, even, parabolic-shaped, variable and end-spurt pacing strategies (Tucker & Noakes, 2009; Abbiss & Laursen, 2008). This was evident in the findings of Waldron et al. (2013) when analysing movement patterns of elite rugby league players. Although Waldron and colleagues (2013) reported significant decrements in high intensity movements, it was suggested the amount of reduction varied depending on the duration players spent on the pitch and advocated that pacing strategies were employed, particularly by interchange players. Whole match players showed a steady decline in HIR from the first to fourth quarter (~ 21%), first bout interchange players competed at an unmaintainable very high intensity followed by a decline in HIR for the rest of the duration of the bout and were therefore proposed to employ an ‘all-out’ strategy, and the second bout players displayed more of an ‘even’ or in some cases ‘end-spurt’ effort. However, this appears to be sport-specific as an investigation into AFL elite players by Aughey (2010) rejected the concepts that players pace their efforts during matches, as no differences were evident in total distances or in distances covered at speeds of low intensity. Although, following the most recent review of fatigue and pacing in team sports, Waldron and Highton (2014) suggested a ‘slow-positive’ pacing effort is typically a global response across all team sports when whole match players are considered. Indeed, research into soccer and rugby league has denoted performance in the first half of matches affects players' abilities to maintain high intensity activity in the second half (Bradley & Noakes, 2013; Sirotic et al., 2009), with a large involvement in HIR in the first half causing a notable reduction in HIR in the second half (Bradley & Noakes, 2013). Moreover, researchers have suggested other factors can also play a part in player profiles, such as the game outcome and its score line (Bradley & Noakes, 2013), standard of opposition (Mohr et al., 2003; Rampinini, Bosio, Ferraresi, Petruolo, Morelli & Sassi, 2011), fitness levels (Mohr et al., 2005), seasonal differences (Rampinini et al., 2009) and environment (Brenner, Zamecnik, Shek, Shephard, 1997; Waldron & Highton, 2014).

The findings in soccer have also shown a reduction in HIR is often identified briefly following the most intense periods of the game, suggesting that transient fatigue exists (Carling & Dupont, 2011; Mohr et al., 2003; Bradley & Noakes, 2013). However, at present research investigating elite rugby union, particularly the English Premiership, is limited with few studies addressing any aspects of fatigue. Of the work published so far, the data sets are notably small, typically combining all positions together, and more representative of individual player styles than individual positional demands. Additionally, considering the onset of fatigue is speculated to increase a player's susceptibility to injury (Brooks, Fuller, Kemp & Reddin, 2005; Brooks et al., 2008), a further understanding of match play, particularly how movement changes throughout a game and what likely reflects fatigue and/or pacing would be extremely beneficial for practitioners and academics.

2.10 Conclusion

Despite there being a relatively broad knowledge base of rugby union and its physical demands, with advancements in micro technologies, the use of GPS can enable a comprehensive, contemporary analysis of the elite game. Previously, the physical demands of elite rugby union have primarily been assessed through video-based time-motion analysis techniques and whilst the literature has demonstrated that such techniques are capable of accurately determining movement demands, the limitations accompanying them inhibit the analysis of large samples, predominantly due to time constraints of analysis. However, notwithstanding its own limitations, GPS developments have the capability of reducing the time restrictions associated with video-based TMA, making it much more feasible to investigate larger, more representative data sets, enabling a greater understanding of individual positional demands. To-date, at the elite level, only a handful of studies have sought to quantify the demands of the game through GPS, which have presented information in the main as a case study, providing data from one match on two players (Coughlan et al., 2012; Cunniffe et al., 2009) up to eight players (Reid et al., 2013) or from three matches (Suarez-Arrones et al., 2012). However, considering it has been suggested a minimum of between three and seven games must be analysed to profile match play in team sports (Eaves, Hughes & Lamb, 2005; Hughes et al., 2001; Vivian et al., 2001), it is unlikely the results of these earlier findings are representative of match demands (Coughlan et al., 2012; Cunniffe et al., 2009; Reid et al., 2013; Suarez-Arrones et al., 2012). Moreover, whilst the findings of Jones et al. (2015) are more representative as they are based on a larger sample size, still no studies exist when GPS has been used to investigate specific demands of the English Premiership.

Furthermore, within the TMA and GPS investigations researchers have tended to group playing positions, typically into forwards and backs and four groups (Austin et al., 2011b; Deutsch et al., 1998; Deutsch et al., 2007; Duthie et al., 2005; Duthie et al., 2006; Lacome et al., 2014; Roberts et al., 2008; Venter et al., 2011). However, the findings of Eaton and George (2006) and Quarrie et al. (2013) have highlighted differences are present within such positional groups and proposed the need to investigate the demands of the individual positions. Yet, across the literature there are currently no studies that have analysed all fifteen positions in the English Premiership. Moreover, very few authors have attempted to combine all elements of the game, characteristically assessing either locomotive movement or performance elements of the game, particularly at the elite level, but not both. Additionally, few researchers have examined the changes in movement profiles of players (Jones et al., 2015), particularly incorporating static exertions.

Of the body of literature available, a considerable amount is based on match demands from the early part of the 21st century, however, more recent analysis of the southern hemisphere game has implied that the game has evolved since then, principally reflected by the greater physical demands of faster play (Austin et al., 2011b). It is therefore conceivable that this is also the case in the northern hemisphere game, but evidence is lacking. Therefore, conducting such research has the potential to allow practitioners, sport scientists and coaches to enhance their understanding of the contemporary English Premiership demands by position, develop their knowledge of movement profiles throughout match play and essentially aid in devising position-specific training programmes which will prepare players optimally for competition.

Chapter 3: Establishing an Appropriate Classification of Locomotive Speed in Rugby Union Performance Analysis

3.1 Introduction

The earliest publication in sports notation is considered to be by Fullerton, 1910 (Eaves & Worsfold, 2014; Hughes & Franks, 2004), although it is believed analysis into baseball was conducted by Henry Chadwick as early as 1859 (Eaves, 2013, cited in Eaves & Worsfold, 2014). Indeed it is thought Maurice Martin and Fernand Bidault produced the first analysis of an elite game of rugby union in 1907 when reporting on the French final Paris versus Bordeaux (Humbert, 2010, cited in Eaves & Worsfold, 2014). The investigation provided an extensive breakdown of the key game actions inclusive of the time and area on the pitch they occurred. However, until recently, few researchers have continued to present such comprehensive analysis of sports and indeed of the modern rugby union game. Over the last decade the movement characteristics and key performance indicators of team sports, including rugby union, have received considerable research focus. Analysis has primarily taken the form of TMA (Austin et al., 2011b; Deutsch et al., 1998; Deutsch et al., 2007; Duthie et al., 2003; Duthie et al., 2005; Duthie et al., 2006; Eaton & George, 2006; Lacome et al., 2014; Quarrie et al., 2013; Spencer et al., 2009; Skyes et al,. 2009; Sykes et al., 2011), notational analysis (Hughes et al., 2012; James et al., 2005; Jones et al., 2004; Lim et al., 2009; Ortega et al., 2009; van Rooyen et al., 2006; Vaz et al., 2011) and most recently, GPS analysis (Aughey, 2012; Coughlan et al., 2011; Cunniffe et al., 2009; Gabbett, 2012, 2013a, 2013b; Hartwig et al., 2011; Jones et al., 2015; McLaren et al., 2015; McLellan et al., 2011a; McLellan et al., 2011b; Reid et al., 2013; Waldron et al., 2011b; Wisbey et al., 2010).

Utilising the early pivotal work of Fullerton (1910), Reilly and Thomas (1976) built on the development of sports analysis and aided in sculpturing TMA methodologies, primarily in soccer, but notably across all team sports. In accordance with the earlier investigations, Reilly and Thomas (1976) proposed in order to gain an understanding of the physical demands (of soccer) during both competition and training analysis of distances covered by players, with further explorations of the distances travelled in different velocity categories ('intensities'), should be conducted. Moreover, Reilly and Thomas classified velocities (speeds[1]) as 'standing', 'walking', 'backwards movements' and 'running', with additional categories for running, such as 'jogging', 'cruising' and 'sprinting'. These different movement intensities were identified subjectively through the use of locomotive observation, a stop-watch and specific cues presented on the pitch. Though constrained by rather basic data capture techniques (relative to 21st century capabilities), this template has remained in-tact over the decades and has been adopted in many of the investigations cited above. However, a notable source of variance has occurred in the definition of the speed classifications (and their discrete boundaries), leading to difficulties in conducting meaningful between-study comparisons.

It is apparent that a few key studies have fashioned the classification of locomotive categories in terms of the labels and speeds associated with them. Reilly and Thomas (1976) labelled their locomotive patterns based on subjective observations, but Bangsbo et al. (1991) were the earliest to allocate predetermined running speeds to classify different movement intensities (see Table 3.1). Bangsbo et al. filmed fourteen professional soccer players who were instructed to walk, jog, run at 'low', 'medium', and 'high' speeds, and sprint. This was subsequently coupled with match footage in order to identify speed categories representative of such movements. In the manner of Reilly and Thomas (1976), Bangsbo et al. (1991)

[1] The terms 'speed' and 'velocity' are used interchangeably throughout this study.

proposed that it was important to distinguish the distances travelled at high and low intensities as it had been recognised that such distances, particularly at high intensity running, were reflective of the physiological demands of soccer matches and its effects on players.

Research undertaken subsequently by Rampinini et al. (2007a) presented notable variations to this classification when applied to their analysis of the demands of soccer matches. Although they also assigned predetermined speed classifications to categorise running into six discernible variables (standing, walking, jogging, running, high speed running and sprinting) and segmented the running categories into low, high and very high intensity activity (Table 3.2), Rampinini et al. (2007a) provided little explanation as to how they established their speed classifications, or indeed, why they were different to those of Bangsbo et al. (1991). It is somewhat surprising that as the speed classifications in the above appear to have been defined arbitrarily (and clearly based around soccer movements), many researchers assessing the physical demands of other team sports (including contact sports such as rugby union and rugby league) via TMA or GPS techniques, have adopted them without considering their appropriateness.

Table 3.1 Original (soccer) locomotive classifications identified by Bangsbo et al. (1991).

Movement	Speed ($km \cdot h^{-1}$)	Intensity
Standing	0	Standing
Walking	6	Walking
Jogging	8	Low Intensity Running
Low Speed Running	12	Low Intensity Running
Moderate Speed Running	15	High Intensity Running
High Speed Running	18	High Intensity Running
Sprinting	30	High Intensity Running
Backwards Running	12	Low Intensity Running
Other (Heading and Tackles)		

Table 3.2 Alternative (soccer) movement classifications devised by Rampinini et al. (2007a).

Movement	Speed ($km{\cdot}h^{-1}$)*	Intensity
Standing	0 - 0.7	Standing
Walking	0.7 - 7.2	Walking
Jogging	7.2 - 14.4	Low Intensity Running
Running	14.4 - 19.8	High Intensity Running
High Speed Running	19.8 - 25.2	Very High Intensity Running
Sprinting	> 25.2	Very High Intensity Running

*It is noteworthy that these boundaries (as published) overlap.

In rugby union, both subjective descriptors of movements and predetermined speed classifications have been used. Early studies of Docherty et al. (1988) and McLean (1992) adapted Reilly and Thomas's (1976) classification to include standing, walking, jogging, running, sprinting and non-running intense activity (Table 2.3), whereas Duthie et al. (2005), Deutsch et al. (2007) (Table 2.4) and Austin et al. (2011b; Table 2.5) devised their own descriptors.

The most recent work involving TMA (Eaton & George, 2006; Roberts et al., 2008, Table 2.6; Quarrie et al., 2013, Table 2.7) and GPS (Coughlan et al., 2011; Cunniffe et al., 2009; Reid et al., 2013; Table 2.14) has used the specific speed classifications of Bangsbo et al. (1991) and Rampinini et al. (2007a) to investigate movement patterns within rugby union. However, Roberts et al. (2008) in their investigation of elite (English Premiership) rugby union opted to base their locomotive movement classifications on the values defined by Castagna and D'Ottavio (2001), as presented in Table 2.6. Notwithstanding such variance in speed boundaries from study-to-study, an important aspect common to most is the *absolute* nature of these speeds, which takes no account of the capabilities of individual players. For example, what might be classified as 'sprinting' (say, > 20 $km{\cdot}h^{-1}$) could be beyond the usual reach of some players, who would then be deemed to have covered no distance in that movement category during a given match. Similarly, classifying high intensity running (HIR) as movement occurring in the range of 18 – 19.9 $km \cdot h^{-1}$, could mean that certain players would be 'seen' to be engaging in this when in fact they were (for them) 'sprinting' or even 'striding'. In essence, unless all players (in all teams and in all playing positions) are homogeneous in their movement (running) capabilities, then it makes little sense to employ absolute values for classifying their movement patterns.

In recognising the inconsistencies (highlighted above) in the values assigned to the locomotive classifications used in team sports, Dwyer and Gabbett (2012) reviewed the speed ranges of each distinct movement from 125 data sets across five elite sports (men's and women's soccer and field hockey, and Australian rules football) and proposed a consensus of movement classifications for them (presented in Table 2.12). However, they did acknowledge that individualised speed classifications per sport would be a better option, if possible, as their zones were still based on absolute velocities across all positions.

To-date, little research has addressed the important issue of individual speed classifications and relative levels of intensity. Of the few exceptions to this, Abt and Lovell (2009) utilised a physiological variable (the second ventilatory threshold) as a method of determining high intensity running speeds for individual soccer players, and Lacome et al. (2014) identified velocities at maximal aerobic threshold and blood lactate levels of 4 $mmol \cdot l^{-1}$ to determine HIR margins among 30 French international rugby union players. However, individual measures of VO_{2max}, lactate turnpoint and ventilatory thresholds are not only difficult to acquire but also very time consuming and therefore obtaining such measures from a large cohort of professional athletes is not very practical. Venter et al. (2011; Table 3.3) alternatively advocated the technique of defining the boundaries of movement categories on the basis of percentages of *individual* maximal running speeds (Vmax) obtained during match play, which following the introduction of GPS devices can be easily determined in the field of play.

Table 3.3 Locomotive movement classification outlined by Venter et al. (2011).

Movement/Activity	Speed
Stationary	0 – 1 $km \cdot h^{-1}$
Walking	< 20% Vmax*
Jogging	20% – 50% Vmax
Striding	51% – 80% Vmax
Sprinting	81% - 95% Vmax
Maximum Sprinting	96% - 100% Vmax

*Where Vmax equals individual maximal running speed obtained from match play analysis

Whilst these particular zones were used on elite under-19 rugby union players from a relatively small sample size (*n* = 17), they have the intrinsic potential to inform the large scale investigation into the physical match demands of professional rugby union that is the bedrock of this thesis. Indeed, when investigating decrements in high intensity efforts following the most intense periods of play during elite level soccer, Di Mascio and Bradley (2013) acknowledged the vitality of identifying individualised speed thresholds for players based on either anaerobic threshold measurements (as utilised by Abt & Lovell, 2009) or individual sprinting speeds which have previously been used when comparing senior and adolescent soccer players (Harley, Barnes, Portas, Lovell, Barrett, Paul & Weston, 2010). The inclusion of the approach of Venter et al. could elucidate important position-related differences in external load, or indeed similarities, which might have been overlooked by the absolute movement classifications previously used. Indeed, using a similar approach to

Venter et al. (2011), Reardon, Tobin and Delahunt (2015) reported that substantial disparities across positions were evident in distances travelled at high running speeds when an absolute speed (5 $m{\cdot}s^{-1}$) was compared to an individualised speed threshold among 36 elite rugby union players (participating in the RaboDirect Pro12 competition). However, it remains that little consideration has been given to the impact on either the magnitude of absolute (m) or relative ($m{\cdot}min^{-1}$) distances travelled at high intensity or sprint running of applying different speed classifications frequently used in rugby union. Therefore, the purpose of this study was to use GPS data collected across all 15 playing positions from matches played in the English Premiership over three seasons (2010 - 2013) to examine the effects of using individualised speed zones, compared to several commonly used standardised absolute speed classifications, on the amount of HIR and sprinting observed in elite rugby union matches, and thereby determine if it is suitable for subsequent performance analysis of elite rugby union.

3.2 Methods

3.2.1 Participants

Eight professional clubs from the English Premiership volunteered to participate in a nationwide investigation into the playing demands of elite rugby union players using GPS technology. The participation of 188 players (age 26 years; body mass 104 ± 12 kg; stature 1.87 ± 0.07 m) was voluntary, which was verified via their signed informed consent each season. Only players who started the match were included and if a player moved position throughout the match or was sin-binned this GPS file was excluded. If a single player objected to his team mates or opposing players wearing GPS units during matches, this prohibited any other player or team wearing them. The study was approved by the Faculty of Applied Sciences Research Ethics Committee.

3.2.2 Procedures

All matches took place between September 2010 and May 2013 and were played on fifteen different grounds used by the participating English clubs. Each of the eight participating clubs nominated a strength and conditioning coach or sports scientist to be responsible for providing and fitting each participant with a GPS unit on match day. Each consenting player wore a GPS unit (mass = 86 g; size = 0.8 x 0.4 x 0.2 cm; SPI Pro, GPSports, Canberra, Australia) in a padded protected harness, positioned in the area of the upper thoracic spine, between the left and right scapulae. The GPS units captured data at a sampling frequency of 5 Hz and had an inbuilt tri-axial accelerometer, sampling at a rate of 100 Hz. The GPS technology provided information on the position, distances travelled/displacement, speed (across five speed zones, adjusted in accordance with those of Venter et al. post-data collection), and accelerations. The reliability of the GPS unit has previously been shown to be acceptable for measuring speed and distances in team sports (Coutts & Duffield, 2010; Petersen et al., 2009; Waldron et al. 2011a). All participants were familiarised with the devices during training sessions prior to wearing them in matches.

GPS data were collected from all players who opted to wear a GPS unit during match play irrespective of whether they started the match or were brought on as a replacement player. Following each match, the data were imported into the accompanying software package (Team AMS) and then exported out into Microsoft Excel (version 10) for analysis. The highest speed each player attained during matches (across all three seasons) was identified and used as their maximum running speed (or velocity, as referred to in previous studies). Strictly speaking, this was their *match-related* Vmax, as ‘true’ Vmax was not purposely assessed beyond the match environment. Therefore, it was termed peak velocity (Vmax). Subsequently, in accordance with the methods employed by Venter et al. (2011), running at 51 – 80% Vmax was classified as HIR, and running at ≥ 81% Vmax was considered to be 'sprinting'. Particular attention was paid to these two zones as typically researchers have focused on distances at or above HIR speeds as being reflective of the intensity of the game (Mohr et al., 2003).

Typical absolute (m) and relative distances ($m \cdot min^{-1}$) covered in 15 individual playing positions and 6 sub-groups (front row, second row, back row, scrum half, inside backs and outside backs) from a total of 345 GPS files from one season (2010 - 2011) were determined via four speed classification methods; three incorporating the popular absolute speed classifications used in rugby union research (Cunniffe et al., 2009; Eaton & George, 2006; Roberts et al., 2008), plus the individualised classification of Venter et al. (2011).

3.2.3 Statistical Analyses

Descriptive statistics (mean ± SD) were calculated for Vmax in each of the 15 discrete positions and by six positional groups. Separate one-way ANOVAs followed by post-hoc Tukey tests were conducted to identify significant differences in Vmax, HIR speed and sprint speed between individual positions and positional groups. Additional separate one-way ANOVAs followed by post-hoc Tukey tests were conducted to determine if any substantial differences existed in distances travelled in HIR and sprinting when different speed categories were applied. The alpha level was adjusted (where necessary) via the Bonferroni technique in order to offset the increased risk of a type I error that accompanies multiple comparisons.

3.3 Results

Analysis of the mean Vmax values (see Tables 3.4 and 3.5) revealed a significant effect of individual positions ($F = 18.0$, $P \leq 0.0005$) and positional groups ($F = 39.1$, $P \leq 0.0005$). In most cases, post-hoc analysis revealed significant differences ($P \leq 0.0005$) between pairs of (the 15) individual positions and pairs of the six sub-groups ($P \leq 0.003$). For example, on average, the wing positions (Table 3.4, see Appendix 4.1 for significant differences) attained the highest peak speeds during matches, with the left wing (34.76 ± 1.72 km·h^{-1}) and right wing (33.84 ± 2.08 km·h^{-1}) being 28% and 26% respectively, faster than the slowest position, the tighthead prop (25.06 ± 2.31 km·h^{-1}). Likewise, the largest discrepancy (-22%) in the six positional groups was evident between the front row positions (26.31 ± 2.67 km·h^{-1}) and the outside backs (33.65 ± 2.13 km·h^{-1}) (Table 3.5 see Appendix 4.2 for significant differences).

Table 3.4 Descriptive statistics of Vmax (km·h^{-1}) by individual positions.

	Position	*N*	Positional Groups	Mean	SD
1	Loosehead Prop	18	Front Row	26.25	2.47
2	Hooker	12	Front Row	28.06	2.73
3	Tighthead Prop	16	Front Row	25.06	2.31
4	Left Lock	11	Second Row	27.66	2.19
5	Right Lock	14	Second Row	26.92	2.41
6	Blindside Flanker	13	Back Row	28.96	2.15
7	Openside Flanker	13	Back Row	30.26	2.19
8	Number 8	8	Back Row	28.20	3.34
9	Scrum Half	15	Scrum Half	31.57	2.63
10	Fly Half	11	Inside Back	28.20	3.19
11	Left Wing	9	Outside Back	34.76	1.72
12	Inside Centre	6	Inside Back	31.08	2.13
13	Outside Centre	13	Inside Back	31.78	2.88
14	Right Wing	17	Outside Back	33.84	2.08
15	Full Back	12	Outside Back	32.55	2.21

Table 3.5 Descriptive statistics of Vmax (km·h^{-1}) by six positional groups.

Positional Groups	*N*	Mean	SD
Front Row	46	26.31	2.67
Second Row	25	27.25	2.25
Back Row	34	29.28	2.51
Scrum Half	15	31.57	2.63
Inside Backs	30	30.33	3.19
Outside Backs	38	33.65	2.13

Table 3.6 Descriptive statistics of high intensity running (HIR) speed ($km{\cdot}h^{-1}$) and sprint speed ($km{\cdot}h^{-1}$) by individual position.

	Position	*n*	Positional Group	HIR Mean	HIR SD	Sprint Mean	Sprint SD
1	Loosehead Prop	18	Front Row	13.39	1.26	21.26	2.00
2	Hooker	12	Front Row	14.31	1.39	22.73	2.21
3	Tighthead Prop	16	Front Row	12.78	1.18	20.30	1.88
4	Left Lock	11	Second Row	14.02	1.12	22.41	1.77
5	Right Lock	14	Second Row	13.73	1.23	21.81	1.95
6	Blindside Flanker	13	Back Row	14.77	1.10	23.46	1.74
7	Openside Flanker	13	Back Row	15.43	1.12	24.51	1.78
8	Number 8	8	Back Row	14.38	1.71	22.84	2.71
9	Scrum Half	15	Scrum Half	16.10	1.34	25.58	2.13
10	Fly Half	11	Inside Back	14.38	1.62	22.84	2.58
11	Left Wing	9	Outside Back	17.73	0.88	28.15	1.39
12	Inside Centre	6	Inside Back	15.85	1.09	25.18	1.73
13	Outside Centre	13	Inside Back	16.21	1.47	25.75	2.33
14	Right Wing	17	Outside Back	17.26	1.06	27.41	1.68
15	Full Back	12	Outside Back	16.60	1.13	26.37	1.79

Table 3.7 Descriptive statistics of high intensity running (HIR) speed ($km{\cdot}h^{-1}$) and sprint speed ($km{\cdot}h^{-1}$) by six positional groups.

Positional Groups	*n*	HIR Mean	HIR SD	Sprint Speed Mean	Sprint Speed SD
Front Row	46	13.42	1.38	21.31	2.19
Second Row	25	13.90	1.17	22.07	1.86
Back Row	34	14.93	1.30	23.12	2.07
Scrum Half	15	16.10	1.34	25.58	2.13
Inside Backs	30	15.47	1.65	24.57	2.63
Outside Backs	38	17.16	1.10	27.26	1.75

Using the classifications of Venter et al. (2011), Table 3.6 (see Appendix 4.3 for significant differences) reveals how the speeds corresponding to “high intensity running” and “sprinting” differed considerably across the individual playing positions (F = 18.0, $P \leq 0.0005$). In particular, the highest mean speeds for both HIR and sprinting were generated by the left wing (17.73 ± 0.88 $km{\cdot}h^{-1}$ and 28.15 ± 0.86 $km{\cdot}h^{-1}$, respectively) and right wing (17.26 ± 1.06

$km{\cdot}h^{-1}$ and 27.41 ± 1.68 $km{\cdot}h^{-1}$, respectively) positions, whereas the tighthead prop averaged the lowest speeds (12.78 ± 1.18 $km{\cdot}h^{-1}$ and 20.30 ± 1.88 $km{\cdot}h^{-1}$, respectively). HIR and sprinting speeds were 25-28% lower for the loosehead and tighthead prop positions compared to the left wing position and 17% lower than the openside flanker. Similarly, mean HIR and sprint speeds differed by 19% for the fly half and left wing position. Additionally, within-group differences were evident, such as 7% between back row players and 11% between inside and 6% between outside backs. As demonstrated in Table 3.7 (see Appendix 4.4 for significant differences), significant variations existed between the six positional groups (F = 39.1, $P \leq 0.0005$), the greatest differences in mean HIR and sprint speeds being between the front row and outside backs (22%). Moreover, the running speeds for the outside backs were faster than each of the other five positional groups, with the exception of the scrum half position.

Tables 3.8 - 3.9 (see Appendix 4.5 and 4.6 respectively for significant differences) illustrate that the mean total distances travelled in HIR and sprinting varied substantially depending on the speed classification used. Compared to the relative classification of Venter et al. (2011), the three classifications involving absolute speeds markedly under- or over-estimated the distances travelled for all 15 individual and six positional groupings. Tables 3.8 and 3.9 show the largest variations were evident in the number 8 position; when the Cunniffe et al. (2009) classification was applied, the number 8 players covered an average of 749.0 m (~ 5.2 times) less than identified by the individualised speed classification, but when calculated by Eaton and George’s (2006) method, they were almost identical (11.3 m). Adopting the Roberts et al. (2008) method, however, suggested that the number 8 covered 575.5 m (2.6 times) less than that of the Venter et al. (2011) method. Likewise, substantial differences were observed when absolute sprinting speeds were employed, albeit less pronounced than HIR. The most notable differences were apparent between the individualised thresholds and that of Cunniffe et al.

(2009), where, for example, the right wing position covered an average of 408.6 m (7.2 times) more distance whilst sprinting. Interestingly, the speed categories of Eaton and George (2006) suggested the tighthead and loosehead prop covered only 1.1 m and 3.3 m sprinting during competitive matches, compared to 28.6 m and 38.0 m when the individual peak speed-based values were considered.

Among the six positional groups, the largest discrepancy in HIR was manifested in the back row positions (Table 3.12, see Appendix 4.9 for significant differences), where the Cunniffe et al. (2009) and Eaton and George (2006) methods calculated that they covered 711.4 m (4.5 times) less and 102.2 m (1.1 times) more in HIR running, respectively, than the Venter et al. method. In terms of sprinting (Table 3.13, see Appendix 4.10 for significant differences), the outside backs were worst affected, with their mean distances being 354.2 m (7.9 times) and 104.2 m (3.0 times) more via the Cunniffe et al. and Roberts et al. classifications, respectively.

Similarly, notable differences were apparent in *relative* measures of HIR and sprinting ($m \cdot min^{-1}$) when different speed classifications were used for all 15 individual and six positional groups, although with less variance. Tables 3.10 - 3.11 (see Appendix 4.7 and 4.8 respectively for significant differences) illustrated differences were greatest in both HIR and sprint distances ($m \cdot min^{-1}$) when the Cunniffe et al. (2009) classification was applied and most similar when adopting the Eaton and George (2006) method, in comparison to relative individualised Venter et al. (2011) classifications. The greatest difference was evident in the loosehead prop position (when utilising Cunniffe et al., 2009), under-estimating HIR by a mean of 9.6 $m \cdot min^{-1}$ (7.7 times less than individualised thresholds). The largest variation in relative sprinting distance was observed in the right wing position when using classifications of Cunniffe et al. (2009), which over-estimated relative sprint distance by 4.6 $m \cdot min^{-1}$ (7.5 times) more than the individualised speed classifications. When adopting the Eaton and

George (2006) method the greatest similarity in HIR distance was illustrated for the number 8 position (with a difference of 0.2 m·min^{-1}) and the relative sprinting distance for the inside centre position (0.1 m·min^{-1}). In the same manner, when the method of Cunniffe et al. (2009) was applied to the six positional groups, the biggest discrepancy in HIR m·min^{-1} with Venter et al. was found in the front row position (an under-estimation of 9.1 m·min^{-1}; 7.0 times) (Table 3.14; see Appendix 4.11 for significant differences). The largest over-estimation was also presented via the Cunniffe et al. (2009) method for relative sprint measurements, with a difference of 4.0 m·min^{-1} (7.6 times) for the outside backs (Table 3.15; see Appendix 4.12 for significant differences).

Table 3.8 Total distances (m) in HIR when varying speed classifications were applied to individual positions, and differences compared to the individualised speed zones of Venter et al. (2011).

	Total Distance in HIR (m)								Difference in HIR (m)					
	Venter et al. (2011) (HIR 51% - 80% Vmax)		Cunniffe et al. (2009) (HIR 18-20 $km \cdot h^{-1}$)		Eaton & George (2006) (HIR 14.4-25.2 $km \cdot h^{-1}$)		Roberts et al. (2008) (HIR 18-24.1 $km \cdot h^{-1}$)		Cunniffe et al. (2009)		Eaton & George (2006)		Roberts et al. (2008)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1	790.9	219.4	99.0	32.7	575.7	155.2	159.2	62.1	691.8	209.4	215.2	231.5	631.7	215.3
2	758.9	321.1	145.0	64.5	870.1	292.3	246.2	120.3	614.0	274.1	-111.2	238.2	512.8	235.6
3	659.6	336.4	64.7	34.2	418.1	157.0	99.2	56.1	594.9	325.8	241.5	259.0	560.4	322.5
4	765.4	267.3	116.9	54.3	711.2	232.3	201.0	104.2	648.5	252.2	54.2	232.9	564.4	252.9
5	708.7	236.1	93.2	29.5	598.5	145.4	161.1	58.6	615.6	219.9	110.3	184.5	547.6	215.0
6	882.8	308.3	189.9	80.9	951.5	328.8	356.0	151.5	693.0	247.1	-68.7	171.5	526.8	209.5
7	945.6	399.0	232.7	117.2	1146.2	467.8	491.9	237.3	712.9	290.2	-200.6	147.0	453.7	197.1
8	926.6	284.3	177.7	98.1	915.3	377.7	351.2	219.7	749.0	188.7	11.3	132.8	575.5	95.6
9	861.9	347.3	266.4	93.1	1347.8	365.6	499.6	208.2	595.6	290.4	-485.9	275.5	362.3	255.9
10	873.2	220.1	217.0	70.2	1144.4	288.5	431.3	150.7	656.2	161.3	-271.2	139.2	441.9	92.8
11	561.6	224.3	192.9	68.8	896.7	300.4	405.7	139.1	368.7	167.1	-335.2	138.2	155.8	112.9
12	806.4	235.0	246.7	95.7	1270.6	462.1	523.1	183.0	559.7	194.4	-464.2	378.1	283.3	162.3
13	740.3	183.0	212.0	68.2	1097.9	276.9	475.5	127.4	528.3	176.8	-357.7	254.1	264.8	193.8
14	706.4	233.1	196.3	62.3	1033.6	305.5	481.2	159.5	510.1	184.2	-327.2	124.4	225.2	105.4
15	562.3	205.3	174.7	43.5	891.6	219.5	394.4	110.1	387.7	172.5	-329.3	120.7	167.9	119.5
All Positions	767.2	291.5	172.6	92.1	917.2	398.6	346.5	203.9	594.6	249.3	-149.9	319.4	420.7	252.6

Table 3.9 Total distances (m) when varying sprint classifications were applied to individual positions, and differences compared to the individualised speed zones of Venter et al. (2011).,

	Total Distance in Sprinting (m)								Difference in Sprinting (m)					
Position	Venter et al. (2011) (≥ 81% Vmax)		Cunniffe et al. (2009) (>20 km·h^{-1})		Eaton & George (2006) (>25.2 km·h^{-1})		Roberts et al. (2008) (>24.1 km·h^{-1})		Cunniffe et al. (2009)		Eaton & George (2006)		Roberts et al. (2008)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1	38.0	24.7	66.7	37.6	3.3	7.3	6.6	8.2	-28.6	43.3	34.8	26.7	31.5	26.8
2	36.9	34.7	122.3	66.8	15.1	22.7	21.0	26.1	-85.4	54.8	21.8	30.4	15.9	27.4
3	28.6	33.8	37.2	30.6	1.1	2.8	2.7	5.5	-8.6	30.6	27.5	34.3	25.8	32.4
4	35.3	29.6	105.2	64.9	11.2	13.1	21.2	20.9	-70.0	54.5	24.0	21.8	14.1	14.8
5	35.3	36.0	74.8	48.6	3.5	7.9	6.9	13.6	-39.5	22.3	31.8	33.4	28.4	28.7
6	65.4	43.7	208.2	94.6	25.7	20.3	42.0	31.0	-142.8	91.2	39.7	46.2	23.4	49.2
7	79.8	50.4	347.0	162.0	55.7	43.5	87.8	53.1	-267.2	137.7	24.1	39.1	-8.1	40.5
8	61.9	43.5	203.9	141.1	14.1	13.0	30.4	23.0	-142.1	122.8	47.8	39.1	31.4	33.6
9	37.1	46.8	305.0	142.4	50.0	36.7	71.8	45.8	-267.9	150.7	-12.9	53.2	-34.7	60.2
10	66.8	45.7	293.3	123.8	52.1	41.3	79.1	50.9	-226.5	99.1	14.8	16.4	-12.3	14.5
11	31.4	30.6	323.0	115.3	73.5	46.5	110.2	54.9	-291.6	98.4	-42.1	37.9	-78.7	44.9
12	29.4	41.2	335.2	132.6	33.7	26.8	58.8	37.9	-305.8	131.7	-4.3	32.6	-29.4	44.6
13	53.9	46.3	367.3	117.0	68.3	47.1	103.8	60.0	-313.5	112.8	-14.4	45.7	-49.9	55.0
14	65.0	52.6	473.5	166.9	136.8	69.6	188.6	85.4	-408.6	139.9	-71.8	46.1	-123.6	57.5
15	44.5	54.2	356.5	130.7	99.2	59.5	136.8	69.6	-312.1	98.2	-54.8	55.0	-92.3	55.5
All Positions	47.0	44.0	238.9	176.5	43.7	54.2	65.0	71.6	-191.9	163.3	3.4	52.6	-18.0	65.1

Table 3.10 Relative total distance (m·min^{-1}) in HIR when varying speed classifications were applied to individual positions and differences compared to the individualised speed zones of Venter et al. (2011).

	HIR (m·min^{-1})								Difference in HIR (m·min^{-1})					
	Venter et al. (2011) (HIR 51% - 80% Vmax)		Cunniffe et al. (2009) (HIR 18-20 km·h^{-1})		Eaton & George (2006) (HIR 14.4-25.2 km·h^{-1})		Roberts et al. (2008) (HIR 18-24.1 km·h^{-1})		Cunniffe et al. (2009)		Eaton & George (2006)		Roberts et al. (2008)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1	10.9	2.9	1.4	0.4	8.0	2.0	2.2	0.8	9.6	2.8	3.0	3.1	8.7	2.9
2	11.1	5.2	2.1	1.1	12.3	3.6	3.5	1.8	9.0	4.5	-1.2	3.5	7.6	4.2
3	9.8	3.9	1.0	0.5	6.4	2.2	1.5	0.9	8.8	3.7	3.4	3.0	8.3	3.7
4	9.2	3.3	1.3	0.5	8.2	2.0	2.3	1.1	7.9	3.4	1.0	3.4	6.9	3.5
5	9.2	3.2	1.2	0.4	7.8	2.0	2.1	0.8	8.0	3.0	1.5	2.4	7.1	2.9
6	10.5	2.9	2.3	0.8	11.4	3.2	4.3	1.5	8.2	2.3	-0.9	1.9	6.2	2.0
7	11.5	4.6	2.8	1.3	13.9	5.0	5.9	2.6	8.7	3.5	-2.4	1.7	5.6	2.7
8	11.0	2.4	2.0	1.0	10.8	3.7	4.1	2.3	9.0	1.6	0.2	1.7	7.0	0.9
9	10.3	3.9	3.2	1.0	16.1	4.0	6.0	2.3	7.1	3.3	-5.8	3.2	4.3	2.9
10	9.8	2.2	2.4	0.7	12.8	3.1	4.8	1.6	7.3	1.6	-3.1	1.6	5.0	0.9
11	6.8	2.1	2.4	0.8	11.1	3.5	5.0	1.6	4.4	1.6	-4.3	2.3	1.8	1.3
12	9.3	2.3	2.9	1.1	14.7	5.0	6.0	2.0	6.4	1.9	-5.4	4.3	3.2	1.7
13	8.7	2.0	2.5	0.7	12.7	2.6	5.5	1.4	6.2	2.0	-4.1	2.7	3.1	2.2
14	7.9	2.4	2.2	0.7	11.6	3.2	5.4	1.7	5.7	1.9	-3.7	1.4	2.5	1.1
15	6.2	2.0	1.9	0.5	9.9	2.3	4.4	1.1	4.2	1.7	-3.7	1.4	1.8	1.2
All Positions	9.5	3.5	2.1	1.0	11.1	4.2	4.2	2.2	7.4	3.2	-1.6	4.0	5.4	3.4

Table 3.11 Relative total distance (m·min^{-1}) sprinting when varying speed classifications were applied to individual positions and differences compared to the individualised speed zones of Venter et al. (2011).

	Sprinting (m·min^{-1})								Difference in Sprinting (m·min^{-1})					
	Venter et al. (2011) Sprinting (≥ 81% Vmax)		Cunniffe et al. (2009) (> 20 km·h^{-1})		Eaton & George (2006) (> 25.2 km·h^{-1})		Roberts et al. (2008) (>24.1 km·h^{-1})		Cunniffe et al. (2009)		Eaton & George (2006)		Roberts et al. (2008)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1	0.5	0.4	0.9	0.5	0.0	0.1	0.1	0.1	-0.4	0.6	0.5	0.4	0.4	0.4
2	0.6	0.6	1.7	1.0	0.2	0.4	0.3	0.5	-1.1	0.7	0.4	0.6	0.3	0.5
3	0.4	0.4	0.6	0.5	0.0	0.0	0	0.1	-0.2	0.4	0.4	0.5	0.4	0.4
4	0.4	0.4	1.2	0.7	0.1	0.1	0.2	0.2	-0.8	0.6	0.3	0.3	0.2	0.2
5	0.5	0.4	1.0	0.6	0.1	0.1	0.1	0.2	-0.5	0.3	0.4	0.4	0.4	0.4
6	0.8	0.5	2.5	1.0	0.3	0.2	0.5	0.4	-1.7	1.0	0.5	0.5	0.3	0.6
7	1.0	0.6	4.2	1.8	0.7	0.6	1.1	0.7	-3.2	1.5	0.3	0.5	-0.1	0.5
8	0.8	0.5	2.4	1.5	0.2	0.2	0.4	0.3	-1.6	1.4	0.6	0.5	0.4	0.4
9	0.4	0.5	3.7	1.6	0.6	0.4	0.9	0.6	-3.2	1.7	-0.2	0.6	-0.4	0.7
10	0.7	0.5	3.2	1.3	0.6	0.4	0.9	0.5	-2.5	1.1	0.2	0.2	-0.1	0.2
11	0.4	0.3	3.9	1.1	0.9	0.5	1.3	0.5	-3.6	1.0	-0.5	0.4	-0.9	0.5
12	0.3	0.5	3.9	1.4	0.4	0.3	0.7	0.4	-3.5	1.4	-0.1	0.4	-0.3	0.5
13	0.6	0.5	4.3	1.4	0.8	0.6	1.2	0.7	-3.7	1.3	-0.2	0.5	-0.6	0.6
14	0.7	0.6	5.3	1.7	1.5	0.7	2.1	0.9	-4.6	1.5	-0.8	0.5	-1.4	0.6
15	0.5	0.6	3.9	1.4	1.1	0.6	1.5	0.7	-3.5	1.1	-0.6	0.6	-1.0	0.6
All Positions	0.6	0.5	2.8	1.9	0.5	0.6	0.8	0.8	-2.3	1.8	-0.1	0.6	-0.2	0.8

Table 3.12 Total distance (m) in HIR when varying speed classifications were applied to positional groups and differences compared to the individualised speed zones of Venter et al. (2011).

	Total Distance in HIR (m)								Difference in HIR (m)					
Positional Group	Venter et al. (2011) (HIR 51% - 80% Vmax)		Cunniffe et al. (2009) (HIR 18-20 $km{\cdot}h^{-1}$)		Eaton & George (2006) (HIR 14.4-25.2 $km{\cdot}h^{-1}$)		Roberts et al. (2008) (HIR 18-24.1 $km{\cdot}h^{-1}$)		Cunniffe et al. (2009)		Eaton & George (2006)		Roberts et al. (2008)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Front Row	729.6	302.2	100.0	56.0	606.1	280.1	162.9	102.4	629.6	278.1	123.5	289.0	566.7	268.0
Second Row	729.3	246.4	101.8	41.3	639.5	187.4	175.6	79.5	627.5	229.8	89.9	202.6	553.7	226.7
Back Row	914.8	335.6	203.4	99.8	1017.0	400.2	405.7	207.6	711.4	250.6	-102.2	173.4	509.1	190.4
Scrum Half	861.9	347.3	266.4	93.1	1347.8	365.6	499.6	208.2	595.6	290.4	-485.9	275.5	362.3	255.9
Inside Backs	791.6	210.0	221.8	76.1	1152.6	334.6	475.5	149.3	569.8	182.1	-361.0	271.5	316.1	179.3
Outside Backs	632.8	231.8	189.9	59.6	962.6	288.5	439.9	146.7	442.9	186.3	-329.8	124.8	192.9	113.6

Table 3.13 Total distance (m) sprinting when varying speed classifications were applied to positional groups and differences compared to the individualised speed zones of Venter et al. (2011).

	Total Distance Sprinting (m)								Difference in Sprinting (m)					
Positional Group	Venter et al. (2011) Sprinting (≥ 81% Vmax)		Cunniffe et al. (2009) (> 20 km·h^{-1})		Eaton & George (2006) (> 25.2 km·h^{-1})		Roberts et al. (2008) (>24.1 km·h^{-1})		Cunniffe et al. (2009)		Eaton & George (2006)		Roberts et al. (2008)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Front Row	34.0	31.5	72.5	58.3	6.1	14.5	9.6	17.3	-38.6	53.6	27.9	30.9	24.4	29.5
Second Row	35.3	33.5	85.9	56.3	6.3	10.7	12.1	17.8	-50.6	39.6	29.0	29.7	23.2	25.4
Back Row	70.1	46.0	259.1	146.5	34.6	34.2	56.8	46.0	-189	129.4	35.5	42.5	13.2	45.8
Scrum Half	37.1	46.8	305.0	142.4	50.0	36.7	71.8	45.8	-267.9	150.7	-12.9	53.2	-34.7	60.2
Inside Backs	51.3	46.2	339.9	124.3	55.5	43.2	86.2	55.4	-288.6	118.3	-4.2	38.3	-34.9	47.2
Outside Backs	51.2	49.7	405.4	159.4	111.1	66.6	155.4	81.1	-354.2	130.5	-59.9	47.5	-104.2	56.7

Table 3.14 Relative total distances ($m \cdot min^{-1}$) in HIR when varying speed classifications were applied to positional groups and differences compared to the individualised speed zones of Venter et al. (2011).

	HIR ($m \cdot min^{-1}$)								Difference in HIR ($m \cdot min^{-1}$)					
Positional Group	Venter et al. (2011) (HIR 51 – 80% Vmax)		Cunniffe et al. (2009) (HIR 18-20 $km \cdot h^{-1}$)		Eaton & George (2006) (HIR 14.4-25.2 $km \cdot h^{-1}$)		Roberts et al. (2008) (HIR 18-24.1 $km \cdot h^{-1}$)		Cunniffe et al. (2009)		Eaton & George (2006)		Roberts et al. (2008)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Front Row	10.6	4.1	1.5	0.8	8.7	3.7	2.3	1.5	9.1	3.7	1.9	3.8	8.2	3.6
Second Row	9.2	3.2	1.3	0.5	7.9	2.0	2.2	0.9	8.0	3.1	1.3	2.8	7.1	3.1
Back Row	11.0	3.5	2.4	1.1	12.2	4.2	4.8	2.3	8.6	2.7	-1.2	2.0	6.1	2.2
Scrum Half	10.3	3.9	3.2	1.0	16.1	4.0	6.0	2.3	7.1	3.3	-5.8	3.2	4.3	2.9
Inside Backs	9.1	2.1	2.5	0.8	13.2	3.5	5.5	1.6	6.6	1.9	-4.1	3.0	3.6	2.0
Outside Backs	7.2	2.4	2.2	0.7	11.0	3.1	5.0	1.6	5.0	1.9	-3.8	1.7	2.1	1.2

Table 3.15 Relative total distance ($m \cdot min^{-1}$) sprinting when varying sprinting classifications were applied to positional groups and differences compared to the individualised speed zones of Venter et al. (2011).

	Sprinting ($m \cdot min^{-1}$)								Difference Sprinting ($m \cdot min^{-1}$)					
Positional Group	Venter et al. (2011) (Sprinting ≥ 81% Vmax)		Cunniffe et al. (2009) (> 20 $km \cdot h^{-1}$)		Eaton & George (2006) (> 25.2 $km \cdot h^{-1}$)		Roberts et al. (2008) (>24.12 $km \cdot h^{-1}$)		Cunniffe et al. (2009)		Eaton & George (2006)		Roberts et al. (2008)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Front Row	0.5	0.5	1.0	0.8	0.1	0.3	0.1	0.3	-0.5	0.7	0.4	0.5	0.4	0.5
Second Row	0.4	0.4	1.1	0.6	0.1	0.1	0.1	0.2	-0.6	0.4	0.4	0.4	0.3	0.3
Back Row	0.9	0.6	3.1	1.7	0.4	0.4	0.7	0.6	-2.3	1.5	0.4	0.5	0.2	0.5
Scrum Half	0.4	0.5	3.7	1.6	0.6	0.4	0.9	0.6	-3.2	1.7	-0.2	0.6	-0.4	0.7
Inside Backs	0.6	0.5	3.9	1.4	0.6	0.5	1.0	0.6	-3.3	1.3	-0.1	0.4	-0.4	0.5
Outside Backs	0.6	0.5	4.6	1.6	1.2	0.7	1.7	0.8	-4.0	1.3	-0.7	0.5	-1.2	0.6

3.4 Discussion

This study has served to highlight that individual running capabilities (Vmax) varied markedly across the 15 playing positions (by up to 28%), and across six group positions (by up to 22%). Whilst these findings might not be surprising owing to the recognised roles assigned to certain positions and their associated physical characteristics, their implications for the subsequent quantification of players' movements at different intensities during matches (their 'performances') are considerable. In particular, using these values as a benchmark for setting relative movement intensity thresholds (in the manner of Venter et al., 2011), has revealed that the practice of employing absolute values (in the manner of Cunniffe et al., 2009, Eaton & George, 2006, and Roberts et al., 2008) would mis-represent the degree to which players were engaged in the important HIR and sprinting categories (Reardon et al. (2015).

A good example of such disparity is that of the front row and second row players in the current study, whose corresponding mean speeds for HIR were outside the range (lower than) often used in previous research (14.4 – 18 $km{\cdot}h^{-1}$), implying (erroneously), in crude terms, that such players spent little or no match time at such an intensity. Consequently, when the absolute speed thresholds employed in previous studies were applied to the same data set as for the relative (individualised) speed calculation, it emerged that the average HIR distances could be substantially either under- or over- estimated for individual positions and positional groups. Moreover, applying the speed zone outlined by Eaton and George (2006) suggests the outside backs covered five times more metres per minute in HIR than when the speed zone of Cunniffe et al. (2009) was applied (11 versus 2.2 $m{\cdot}min^{-1}$, respectively) and double the amount of metres per minute when the Roberts et al. (2008) classification was utilised (11 v 5 $m{\cdot}min^{-1}$, respectively). Likewise, when comparing the loosehead prop with the scrum half positions, mean differences of 166 m, 741 m and 337 m were calculated when the speed classifications of Cunniffe et al., Eaton and George, and Roberts et al. were employed. Therefore, these findings demonstrate clearly that caution is needed when adopting speed zones, and as such they do not lend themselves to being used interchangeably. Importantly, the selection of speed classifications could potentially have an impact on the interpretation of the data, particularly in the preparation for competition.

Typically, physical training is designed to impose physiological stress on an athlete to induce the required adaptation in order to cope with competition demands (Impellizzeri, Rampinini & Marcora, 2005; Viru & Viru, 2001). However, considering the different fitness levels and match requirements of individual players, utilising absolute movement thresholds to determine match demands and thus inform training could under- or over-estimate the training stimulus required. For example, if a conditioning practitioner was to schedule an overloading training session that was twice as hard as competition expectations, by employing the classification of Cunniffe et al. (2009) it would suggest that the outside backs positions would need to cover approximately 380 m in HIR efforts and ~ 800 m sprinting, compared to ~ 1,265 m and 102 m sprinting if the relative (individualised) classification was used. Moreover, applying the thresholds of Eaton and George (2006) would equate to a prescription of ~ 1,924 m at HIR and 222 m sprinting. Therefore, the application of absolute speed classifications could elicit unwanted training effects, such as inhibiting 'fitter' athletes receiving the stimulus required to make the necessary adaptations to prepare them for competition (Hoff, Wisløff, Engen, Kemi & Helgerud, 2002; Impellizzeri et al., 2005), or encourage a training load greater than anticipated that negatively impacts on fatigue/recovery or even induces overtraining effects in the long term. Accordingly, the use of relative speed classifications takes individual abilities into consideration and facilitates a more accurate monitoring and control of training than absolute thresholds (Abt & Lovell, 2009). Not only this, evidently the selection of speed thresholds is pertinent to the distances covered in different speed classifications. Therefore, that many researchers have not considered these implications and have overlooked the variances in absolute and relative distances when identifying differences in positional demands and competition levels (Eaton & George, 2006; Gabbett, 2013b; Mohr et al., 2003; Roberts et al., 2008; Quarrie et al., 2013) implies a possible misinterpretation of their data. For example, when investigating elite and sub-elite soccer players Mohr et al. (2003) reported that higher level soccer players were involved in covering greater distances at high intensity and sprint speeds of approximately 530 m and 240 m, respectively (28% & 58%). However, since the present findings have illustrated the choice of absolute compared to relative speed classifications can evoke discrepancies of between 485 – 749 m for distances covered in HIR and 123 – 408 m in sprint running when using the same data set, it could be the employment of absolute speed thresholds that is the source of their differences instead of true variations owing to the standard of competitors or playing positions.

The average peak sprint speed for certain individual positions, principally the tighthead prop (25.06 $km \cdot h^{-1}$), was typically lower than the absolute speed classification suggested by Eaton and George (2006) and unsurprisingly, this translates into an average distance covered of only 1.1 m, or 0.0 $m \cdot min^{-1}$ during competitive matches. That the loosehead prop yielded equally low sprinting values (3.3 m 0.0 $m \cdot min^{-1}$) infers that the prop positions rarely 'sprint' during matches. This is unlikely to be the reality. Contrastingly, the use of relative speed classifications identified that mean sprint distances ranged from 28.6 – 38.0 m, or 0.4 - 0.5 $m \cdot min^{-1}$ for the prop positions. Similar discrepancies are evident in the backs, for example when the absolute speed categories of Cunniffe et al. (2009) were utilised, the right wing position was calculated to cover ~ 400 m further sprinting than when the relative sprint measure was used. As the backs are typically able to attain significantly higher peak running speeds than the forwards (as much as ~ 22%), it questions the suitability of using an absolute speed classification across all positions for determining movement patterns accurately. This view has recently been endorsed by Reardon et al. (2015), whose data highlighted the application of an absolute speed threshold for high speed running could indicate the backs covered 2.6 times more distance than the forwards, compared to only 1.6 times when relative individual speed thresholds are employed.

This study has displayed how the widely used high intensity and sprint running speeds vary depending on player position when the relative speed zones of Venter et al. (2011) are utilised. Lower values were typical of the front and second row positions, and higher sprint speeds for the outside backs than the traditional (arbitrary) absolute values that have previously been applied. However, this is consistent with the findings of Abt and Lovell (2009) and Lacome et al. (2014) who reported substantially lower individualised thresholds in comparison to the common absolute classifications when objective physiological measures were employed to identify HIR speeds. Lacome et al. (2014) determined maximal aerobic velocities to identify HIR speeds in the range 14.9 – 16.1 $km \cdot h^{-1}$ across four positional groups (front row, back row, inside backs, outside backs). Similarly, Abt and Lovell (2009) found 15 $km \cdot h^{-1}$ best represented the median speed for HIR in professional soccer players when the second ventilatory threshold was used as an objective marker. Interestingly, the overall average speed (determined via the relative individualised approach of Venter et al., 2011) across all positions in the current investigation was 15.13 $km \cdot h^{-1}$, which is similar to these physiologically-based HIR zones, yet at the low end of Eaton and George's (2006) HIR zone, and 2.9 $km \cdot h^{-1}$ slower than the low point of the HIR zones of Cunniffe et al. (2009) and Roberts et al. (2008). In the context of Dwyer and Gabbett's (2012) recommendations based on five team sports (excluding rugby union) (Table 2.12), the current HIR range (12.78 - 17.73 $km \cdot h^{-1}$) would sit well in their 'running' zone (12.96 - 19.8 $km \cdot h^{-1}$; 3.6 - 5.5 $m \cdot s^{-1}$).

3.5 Practical Applications

The majority of researchers have used absolute speed thresholds to determine movement patterns of rugby union players, particularly to identify their involvement in high intensity and sprint running during competitive match play. However the findings of this study have shown that absolute speed classifications could either under–or over-estimate an individual's involvement in high intensity and sprint running, as individual running capabilities were shown to vary by as much as 28% across the 15 positions. The results suggest it is essential to determine individual player running capabilities prior to monitoring movement, in order to identify personalised high intensity and sprint running thresholds. Ideally such thresholds would be defined through laboratory-based or field-based tests as described elsewhere (Abt & Lovell, 2009; Lacome et al., 2014). However, where this is not feasible the current study has shown the use of the method identified by Venter et al. (2011) ($\geq$ 51% of Vmax represents HIR and $\geq$ 81% of Vmax represents sprinting) can be an acceptable alternative for identifying individual movement patterns in rugby union players when maximal running speed is known.

3.6 Summary

It is evident that when the different physiques and skill sets required per playing position in rugby union are considered, varying degrees of running ability would be expected and intuitively it would seem justified that speed classifications should reflect this. Based on the current findings, it would appear that the method set by Venter et al. (2011) provides an appropriate, non-invasive means of determining individualised relative speed thresholds for monitoring movement patterns in rugby union players. As there is a lack of objectivity in the allocation of percentages of Vmax to the discrete speed zones, and it could be suggested that peak speeds attained during match play are sub-maximal for some individuals, (leading to under-estimates of HIR and sprinting speeds and over-estimates of the distances travelled in these categories) the approach has its limitations. Nonetheless, the average maximum speed across all positions was calculated as 29.75 km·h^{-1} (8.26 m·s^{-1}) which is very similar to the average 'true' maximum running speed (8.3 m·s^{-1}) determined by Reardon et al. (2015). Therefore, it is the author's view that this approach is an acceptable, alternative to those that have proliferated so far, and given the scale of position-related differences highlighted above, it is the logical choice for the remainder of the programme of research that follows.

Chapter 4: The Movement Characteristics of English Premiership Rugby Union Players

Paper published using data from this chapter: Cahill, N., Lamb, K., Worsfold, P., Headey, R., & Murray, S. (2013). The movement characteristics of English Premiership rugby union players. *Journal of Sports Sciences, 31*(3), 229- 237

4.1 Introduction

Following its emergence as a professional sport in 1995, performance analysts have endeavoured to quantify rugby union's physical demands (Duthie et al., 2003) predominantly through the use of time-motion analysis (Deutsch, et al., 1998; Deutsch, et al., 2007). Such knowledge is deemed valuable to coaches and scientific support staff for enabling simulation in a training environment, permitting optimal player conditioning and match preparation (Gabbett, 2010; Rushall & Pyke, 1990). The earliest time-motion analysis (TMA) findings from the northern (Eaton & George, 2006; Roberts et al., 2008), and southern hemispheres (Austin et al., 2011a, Austin et al., 2011b; Deutsch et al., 1998; Deutsch et al., 2007; Duthie et al., 2005;), and at the international standard (Lacome et al., 2014; Quarrie, et al., 2013), established that rugby union is a game dominated by activity at low intensities but separated by intermittent periods of high intensity movements (Austin et al., 2011a).

Positional differences in such 'game demands' have been explored generally between the backs and the forwards (Deutsch et al., 1998; Deutsch et al., 2007; Duthie et al., 2005). For example, backs have been shown to spend more time (94%) in low intensity activity (< 12.96 $km \cdot h^{-1}$) than forwards (88%; Roberts et al., 2008). Additionally, four positional groups (props and locks, back row and hookers, inside backs and outside backs) have been defined and a number of movement variables were compared (Deutsch et al., 1998; Duthie et al., 2005; Roberts et al., 2008), revealing little notable differences. However, Deutsch et al. (1998) reported variations within the backs among under-19 year olds, in particular that the outside backs covered significantly more distance whilst sprinting (running with maximal effort) than the inside backs (208 m versus 340 m). Lacome et al. (2014) reported international back rowers were involved in a greater number of ‘high’ (exceeding 3 $m{\cdot}s^{-2}$) accelerations than the inside backs. Furthermore, Eaton and George (2006) found considerable differences in the movement characteristics of props and locks, especially during certain aspects of play such as lineouts and argued that these two positions should not be combined and analysed as part of a larger group.

As the analysis procedures used in TMA have proved to be time consuming, very costly (Di Salvo et al., 2006; Roberts et al., 2008) and provided predominantly subjective measures of locomotive and ‘static’ intensities (Cunniffe et al., 2009), the development of Global Positioning Systems (GPS) has been welcomed as providing an accurate, non-invasive alternative technique for quantifying the movement characteristics of team sports (Waldron et al., 2011a; Petersen et al., 2009; Coutts & Duffield, 2010). In particular, they are able to monitor movements performed at various intensities across multiple positions simultaneously. However, to the author’s knowledge only a handful of GPS-based studies have assessed the movement patterns of elite level rugby union players (Coughlan et al., 2011; Cunniffe et al., 2009; Jones et al., 2015; Reid et al., 2013; Suarez-Arrones, et al., 2012). Similar to the TMA study of Roberts et al. (2008), these investigations demonstrated that backs travelled further than forwards (7,227 m versus 6,680 m, respectively; Cunniffe et al., 2009) and the backs entered the highest running speed zones (24.1 – 36.0 $km{\cdot}h^{-1}$) more times than the forwards (16 versus 3, respectively; Coughlan et al., 2011), with the wing position attaining the greatest peak speed (31·1 $km{\cdot}h^{-1}$) (Reid et al., 2013). However, a major limitation of all the GPS studies to date was that their analyses were confined to very small sample sizes ranging between two and eight players from one match, with the most fourteen players from three matches (Suarez-Arrones, et al., 2012) illustrating individual playing styles rather than the typical demands of the positions. Clearly, there is scope for a larger-scale investigation that can present a more representative description of the locomotive characteristics of players engaged in elite rugby union competition. Therefore, the aim of this longitudinal study was to utilise GPS to generate overall and position-related measurements on the movement patterns of elite rugby union players competing in the English Premiership.

4.2 Methods

4.2.1 Participants

Eight professional clubs from the English Premiership volunteered to participate in the study for 3 competitive seasons 2010 - 13 competition. The participation of players was of their own volition, which was verified via their signed informed consent (each season). If it occurred that a single player objected to his team mates or opposing players wearing GPS during matches, this prohibited any player or team wearing GPS units. A total of 207 players (age 27.5 ± 4.2 y; body mass 103.8 ± 12.6 kg; stature 1.87 ± 0.07 m), defined by their playing position (rather than their club affiliation), provided 1092 GPS data files collected from Premiership matches played across the three seasons. Each player provided at least one file, the most being 19 files. The study was approved by the Faculty of Applied Sciences Research Ethics Committee.

4.2.2 Procedures

All the matches took place between September 2010 and May 2013 on a Friday, Saturday or Sunday, and were played on fifteen different grounds used by the participating English clubs. Each of the eight participating clubs nominated a strength and conditioning coach or a sports scientist to be responsible for providing and fitting each participant with a GPS unit on match day. Each consenting player wore a GPS unit (mass = 86 g; size = 0.8 x 0.4 x 0.2 cm) (SPI Pro, GPSports, Canberra, Australia) in a padded protected harness, positioned in the area of the upper thoracic spine, between the left and right scapulae. The GPS device captured data at a sampling frequency of 5 Hz and had an inbuilt tri-axial accelerometer, sampling at a rate of 100 Hz. All participants were familiarised with the devices during training sessions prior to wearing them in matches.

The GPS units were switched on at least 10 minutes prior to the game to ensure a full satellite signal was received. At the end of each match the GPS data files were downloaded onto a personal computer and analysed with Team AMS software (version 10; GPSports, Canberra, Australia). A note of the Greenwich Mean Time at the beginning and end of the match was made and later synchronised with the GPS raw data, as was the time if a player was substituted, enabling a subsequent calculation of the length of time spent on the pitch by each player. The raw data files were later segmented into full match, first and second halves, then initially exported into Microsoft Excel (Microsoft Corporation, USA), and subsequently SPSS (version 21) for statistical analyses. Analysis of substitution times across the whole Premiership was noted and later used to determine the average substitution time per position. GPS data files were only included if a player had spent time on the pitch greater than or equal to the average substitution time for his playing position.

4.2.3 Player groupings

For the purposes of data analysis and comparisons with previous studies, the players were grouped using three different classification systems. First, each was labelled as either a forward (loose-head prop, hooker, tight-head prop, left lock, right lock, blind side flanker, open side flanker, and number eight) or a back (scrum half, fly half, left wing, inside centre, outside centre, right wing, and full back). Secondly, they were assigned to one of six positional groups (adapted from Deutsch et al., 2007; Duthie et al., 2005; Roberts et al., 2008), but with the scrum halves assigned a category of their own due to their unique role within the game (Deutsch et al., 2007; Duthie et al., 2005; Roberts et al., 2008). Thus, the groups were as follows: front row (loose-head prop, hooker, tight-head prop; second row (left lock, right lock); back row (blindside flanker, openside flanker, and number eight); scrum half; inside backs (fly half, inside centre, and outside centre) and outside backs (left wing, right wing, and full back). Thirdly, they were categorised by their individual positions, ranging from numbers 1–15 (1, loose-head prop; 2, hooker; 3, tight-head prop; 4, left lock; 5, right lock; 6, blind side flanker; 7, open side flanker; 8, number eight; 9, scrum half; 10, fly half; 11, left wing; 12, inside centre; 13, outside centre; 14, right wing; 15, full back).

4.2.4 Locomotive variables

The total distance (m) and relative distance ($m \cdot min^{-1}$, measured relative to time on the pitch) covered per match per player were calculated along with the maximum speed and average speed. The same variables were quantified in the five speed/movement categories outlined by Venter et al. (2011), and described in Chapter 3, which were based upon the percentage of each player's maximum running speed (Vmax) attained during any game played throughout the seasons (a player's Vmax was determined as the peak speed recorded via the GPS devices). That is, < 20% Vmax (standing and walking), 20 - 50% Vmax (jogging), 51 - 80% Vmax (striding, HIR), 81 - 95% Vmax (sprinting) and 96 - 100% Vmax (maximum sprint).

4.2.5 Statistical Analyses

In recognising that not all the players completed the full 80 minutes of any given game owing to substitutions, data were only analysed for those who played a minimum of the average substitution time for their playing position ((1) loosehead prop – 64 minutes; (2) hooker – 65 minutes, (3) tighthead prop – 62 minutes; (4) left lock – 74 minutes; (5) right lock – 69 minutes, (6) blindside flanker – 73 minutes; (7) openside flanker – 72 minutes; (8) number 8 – 73 minutes; (9) scrum half – 69 minutes; (10) fly half – 74 minutes; (11) left wing – 77 minutes; (12) inside centre – 73 minutes; (13) outside centre – 75 minutes; (14) right wing – 75 minutes; (15) full back – 76 minutes) across the three seasons for the whole of the 2010 - 2013 Premiership competition. Accordingly, 588 GPS files were analysed from 159 players. Initially, diagnostic tests (Shapiro-Wilk and Levene) were performed on the distributions of all the dependent variables to check the assumptions of normality and homogeneity of variance. As most did not satisfy these conditions, non-parametric Mann-Whitney and Kruskal-Wallis hypothesis tests were used to compare variables between forwards and backs, the six pre-defined positional groups and the fifteen individual positional groups, respectively. If appropriate, post-hoc Mann-Whitney tests were used to identify differences between the specific groups. Bonferroni adjustments to the alpha were applied to offset the increased risk of a type I error that occurs when conducting multiple comparisons.

4.3 Results

4.3.1 Forwards and Backs positional groups

Notable differences in movement patterns were identified for the forwards and backs (Table 4.1). The backs moved predominantly (46.3%) in the lowest speed category (standing and walking) whereas the forwards covered most of their distance (46.2%) whilst ‘jogging’. Between-group differences were found to be significant ($P < 0.05$); backs covered greater distances (absolute and relative) and generally moved at higher speeds (maximum and average) than forwards. They also moved more (+ 36.9%) in the standing and walking category, but covered more of their total distance sprinting (+ 35.4%) than the forwards. Finally, a greater proportion of the forwards’ movements were spent in the ‘striding’ category, representing 19.8% more (relative to their total distance) than the backs.

4.3.2 Six positional groups

Analysis of the data illustrated all positional groups covered more than 80% of total distances at speeds less than 50% Vmax (“walking” and “jogging”). With the exception of absolute and relative distances covered at the highest speed category (96 – 100% of Vmax), analysis revealed significant ($P < 0.003$) variability between the six positional groups for all the locomotive measures (see Table 4.2, see Appendix 4.13 for significant differences). Post-hoc analyses highlighted in particular that the scrum half travelled the furthest during matches (and the front row the least; a difference of nearly 2 km, or 41.1%) at the highest average speed (6.4 $km \cdot h^{-1}$).

The outside backs were distinguished by their attainment of the highest peak speeds (31.3 km·h^{-1}) and their movement in the slowest speed category (49.0% of total distance) this being a significantly higher proportion than the other positions.

Table 4.1 Locomotive movement of forwards and backs positions.

Position	Forwards (*n*=274)	IQR	Backs (*n*=314)	IQR
Distances				
Time (min)	89.3^{b}	14.5	90.9^{a}	6.3
Total Distance (m)	5221.8^{b}	1301.5	6134.0^{a}	1086.9
Relative Total Distance (m·min^{-1})	60.9^{b}	8.3	67.9^{a}	12.1
Maximum Speed (km·h^{-1})	25.7^{b}	4.2	30.4^{a}	3.2
Average Speed (km·h^{-1})	6.0	0.8	6.1	0.7
TD at Vmax				
TD < 20% Vmax	1789.4^{b}	630.2	2738.4^{a}	473.7
TD 20 - 50% Vmax	2534.2	613.9	2513.3	743.0
TD 51 - 80% Vmax	820.4	436.9	792.2	390.9
TD 81 - 95% Vmax	28.2^{b}	50.3	40.6^{a}	66.5
TD 96% - 100% Vmax	0.0	2.8	0.0	3.2
% TD at Vmax				
% TD < 20% Vmax	34.7^{b}	8.4	44.3^{a}	8.9
% TD 20 - 50% Vmax	49.3^{b}	6.7	41.6^{a}	7.6
% TD 51 - 80% Vmax	15.6^{b}	6.7	13.0^{a}	5.2
% TD 81 - 95% Vmax	0.6	1.0	0.7	1.1
% TD 96 - 100% Vmax	0.0	0.1	0.0	0.1

Significant difference at P < 0.05. a=Forwards; b = Backs, TD = total distance, < 20% Vmax (standing and walking), 20 - 50% Vmax (jogging), 51 - 80% Vmax (striding, HIR), 81 - 95% Vmax (sprinting) and 96 - 100% Vmax (maximum sprint). Vmax is based upon the percentage of each player's maximum running speed (Vmax) attained during any game played throughout the seasons

Among the three forward groups, the back row players were distinctive in that they covered significantly ($P < 0.003$) more distance (5,797.7 m) and at higher speeds, than the front row (4,638 m) and second row (5,150.9 m). Furthermore, the back row players, who covered a similar amount of distance (44.7 m) to the inside and outside backs, moved significantly more than the front row at 81-95% of Vmax ('sprinting'). The front row players were notable for covering more than 50% of their total distance ‘jogging’, which was significantly greater than any other group ($P < 0.003$) with the exception of the second row.

Table 4.2 Locomotive movement of six positional groups.

Position	Front Row (*n*=103)	IQR	Second Row (*n*=76)	IQR	Back Row (*n*=95)	IQR	Scrum Half (*n*=46)	IQR	Inside Backs (*n*=132)	IQR	Outside Backs (*n*=136)	IQR
Time (mins)	81.9	21.1	89.7	8.4	90.9	6.8	88.9	16.2	91.1	5.1	91.5	5.4
Total Distance (m)	4638	1290.3	5150.9	1017.5	5797.7	892.8	6542.1	1280.3	6202.6	1036.0	5915.9	1055.3
Relative Total Distance ($m \cdot min^{-1}$)	60.0	7.3	58.9	8.7	63.4	8.3	74.2	6.9	68.2	11.3	64.6	10.4
Maximum Speed ($km \cdot h^{-1}$)	24.5	3.6	24.7	2.9	27.8	3.1	28.7	4.4	29.7	3.1	31.3	2.9
Average Speed ($km \cdot h^{-1}$)	6.0	0.8	5.9	0.7	6.2	0.7	6.4	0.5	6.2	0.6	6.0	0.7
TD at Vmax												
TD < 20% of Vmax	1519.3	516.3	1743.0	558.9	2127.2	319.0	2471.3	627.3	2626.3	386.2	2863.7	458.0
TD 20 -50% of Vmax	2451.9	684.6	2578.9	470.6	2633.0	630.9	3008.3	735.6	2615.9	554.7	2252.1	733.8
TD 51 - 80% of Vmax	675.5	475.6	818.6	365.1	929.0	362.4	835.0	448.8	880.2	407.6	696.2	317.7
TD 81 - 95% of Vmax	21.1	36.0	23.6	40.8	44.7	59.1	16.1	32.7	40.4	67.0	52.7	58.8
TD 96 - 100% of Vmax	0.0	2.8	0.0	1.4	0.0	4.6	0.0	1.8	0.0	3.2	0.0	3.7
% TD at Vmax												
% TD < 20% of Vmax	32.5	6.7	33.7	9.8	36.8	5.7	39.5	6.7	42.4	6.6	49.0	9.1
% TD 20 - 50% of Vmax	51.5	5.2	50.2	5.7	46.0	4.9	45.5	6.2	42.5	5.0	36.7	7.6
% TD 51 - 80% of Vmax	14.9	8.6	15.2	7.6	15.9	4.9	13.5	7.4	14.2	5.9	11.9	4.2
% TD 81 - 95% of Vmax	0.4	0.8	0.5	0.8	0.8	1.1	0.2	0.5	0.6	1.0	0.9	0.9
% TD 96 - 100% of Vmax	0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.1

TD = total distance, < 20% Vmax (standing and walking), 20 - 50% Vmax (jogging), 51 - 80% Vmax (striding, HIR), 81 - 95% Vmax (sprinting) and 96 - 100% Vmax (maximum sprint). Vmax is based upon the percentage of each player's maximum running speed (Vmax) attained during any game played throughout the seasons.

Table 4.3 Locomotive movement descriptors of individual positions (1-5).

Position Distances	Loosehead Prop (*n*=31)	IQR	Hooker (*n*=33)	IQR	Tighthead Prop (*n*=39)	IQR	Left Lock (*n*=27)	IQR	Right Lock (*n*=49)	IQR
Total Distance (m)	4949.3	932.6	4871.8	1530.5	4315.7	1142.2	5263.3	1048.6	5092.9	1008.3
Relative Total Distance ($m \cdot min^{-1}$)	60.1	6.7	62.6	9.3	58.3	7.9	58.6	10.4	58.9	8.3
Maximum Speed ($km \cdot h^{-1}$)	24.2	3.4	25.5	5.4	24.0	3.7	25.1	3.6	23.9	2.7
Average Speed ($km \cdot h^{-1}$)	6.2	0.6	6.4	0.6	5.8	0.5	5.8	0.5	5.9	0.7
Total Distance at Vmax										
TD < 20% of Vmax (m)	1485.5	482.4	1577.8	394.6	1417.9	541.6	1880.9	773.3	1712.4	619.4
TD 20 - 50% of Vmax (m)	2614.5	519.5	2525.0	962.0	2179.8	527.2	2561.2	311.7	2630.3	609.4
TD 51 - 80% of Vmax (m)	875.4	332.4	638.7	580.3	560.9	440.4	862.9	301.7	730.2	434.9
TD 81 - 95% of Vmax (m)	28.9	29.4	11.7	42.1	18.4	35.3	22.9	26.3	25.3	49.8
TD 96 - 100% of Vmax (m)	0.0	1.5	0.0	2.3	0.0	4.7	0.0	1.2	0.0	1.4
% Total Distance at Vmax										
% TD < 20% of Vmax (%)	30.1	6.3	33.3	6.4	33.7	9.6	34.7	9.0	33.3	10.5
% TD 20 - 50% of Vmax (%)	51.6	5.0	51.5	6.9	51.3	4.8	48.3	5.2	50.9	4.9
% TD 51 - 80% of Vmax (%)	17.5	5.0	12.4	12.2	14.2	8.1	15.6	6.4	14.0	7.9
% TD 81 - 95% of Vmax (%)	0.6	0.6	0.3	0.9	0.5	0.7	0.5	0.5	0.5	1.0
% TD 96 - 100% of Vmax (%)	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0

TD = total distance, < 20% Vmax (standing and walking), 20 - 50% Vmax (jogging), 51 - 80% Vmax (striding, HIR), 81 - 95% Vmax (sprinting) and 96 - 100% Vmax (maximum sprint). Vmax is based upon the percentage of each player's maximum running speed (Vmax) attained during any game played throughout the seasons.

Table 4.4 Locomotive movement descriptors of individual positions (6-10).

Position	Blindside Flanker	IQR	Openside Flanker	IQR	Number 8	IQR	Scrum Half	IQR	Fly Half	IQR
Distances	(*n*=37)		(*n*=45)		(*n*=13)		(*n*=46)		(*n*=24)	
Total Distance (m)	5874.3	1119.7	5771.5	869.3	5496.8	770	6542.1	1280.3	6449.2	1061.4
Relative Total Distance ($m \cdot min^{-1}$)	63.4	8.3	64.3	8.4	62.4	8.1	74.2	6.9	70.0	9.8
Maximum Speed ($km \cdot h^{-1}$)	27.4	3.2	28.4	3.1	26.4	2.8	28.7	4.4	28.4	3.1
Average Speed ($km \cdot h^{-1}$)	6.3	0.6	6.2	0.8	5.9	0.7	6.4	0.5	6.2	0.8
TD at Vmax										
TD < 20% of Vmax (m)	2103.0	340.2	2148.5	271.2	2018.9	478.2	2471.3	627.3	2499.4	282.7
TD 20 - 50% of Vmax (m)	2664.2	866.3	2638.6	468.8	2423.7	518.1	3008.3	735.6	2842.6	645.6
TD 51 - 80% of Vmax (m)	933.3	345.3	901.9	361.9	860.8	550.8	835.0	448.8	896.6	465.6
TD 81 - 95% of Vmax (m)	47.8	64.5	46.7	62.7	31.0	50.5	16.1	32.7	68.0	57.1
TD 96 - 100% of Vmax (m)	0.0	3.1	0.0	4.8	0.0	6.9	0.0	1.8	2.2	6.1
% TD at Vmax										
% TD < 20% of Vmax (%)	35.8	5.7	37.6	6.4	37.5	3.5	39.5	6.7	40.0	6.8
% TD 20 - 50% of Vmax (%)	47.4	7.1	45.2	3.1	43.2	9.3	45.5	6.2	43.4	4.6
% TD 51 - 80% of Vmax (%)	16.3	4.1	15.7	5.3	15.3	6.9	13.5	7.4	14.8	6.1
% TD 81 - 95% of Vmax (%)	0.9	1.2	0.8	1.0	0.5	0.9	0.2	0.5	1.2	0.8
% TD 96 - 100% of Vmax (%)	0.0	0.1	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.1

TD = total distance, < 20% Vmax (standing and walking), 20 - 50% Vmax (jogging), 51 - 80% Vmax (striding, HIR), 81 - 95% Vmax (sprinting) and 96 - 100% Vmax (maximum sprint). Vmax is based upon the percentage of each player's maximum running speed (Vmax) attained during any game played throughout the seasons.

Table 4.5 Locomotive movement descriptors of individual positions (11-15).

Position Distances	Left Wing (*n=47*)	IQR	Inside Centre (*n=38*)	IQR	Outside Centre (*n=70*)	IQR	Right Wing (*n=49*)	IQR	Full Back (*n=40*)	IQR
Total Distance (m)	5858.4	1093.5	6168.3	1265.8	6136.8	970.8	5963.4	1186.9	6090.7	1161.3
Relative Total Distance ($m \cdot min^{-1}$)	63.1	11.9	68.7	12.6	67.2	11.0	64.2	10.6	66.3	13.2
Maximum Speed ($km \cdot h^{-1}$)	31.4	2.7	28.9	4.0	30.6	3.1	31.5	3.2	30.8	2.6
Average Speed ($km \cdot h^{-1}$)	6.0	0.7	6.2	0.6	6.1	0.6	5.8	0.6	6.0	0.6
TD at Vmax										
TD < 20% of Vmax (m)	2735.4	369.8	2614.1	475.4	2739.2	361.9	2907.8	488.4	2966.3	411.1
TD 20 -50% of Vmax (m)	2249.8	786.8	2631.4	811.3	2588.5	425.4	2179.3	619.2	2356.3	843.3
TD 51 - 80% of Vmax (m)	698.9	217.5	942.6	329.4	830.0	475.8	692.6	359.9	719.4	465.6
TD 81 - 95% of Vmax (m)	46.3	39.5	25.5	53.0	38.9	60.0	64.0	77.7	51.0	78.2
TD 96 - 100% of Vmax (m)	0.0	1.8	0.0	0.0	0.0	5.4	0.0	3.8	0.0	7.1
% TD at Vmax										
% TD < 20% of Vmax (%)	48.3	9.4	40.7	6.4	44.2	6.2	49.9	5.9	47.2	12.8
% TD 20 - 50% of Vmax (%)	37.4	8.8	43.2	7.1	41.6	4.4	35.9	5.7	37.5	10.0
% TD 51 - 80% of Vmax (%)	11.9	3.2	14.2	4.5	13.1	6.9	12.1	4.5	11.5	6.2
% TD 81 - 95% of Vmax (%)	0.8	0.8	0.4	0.9	0.6	1.0	1.1	1.1	0.9	1.0
% TD 96 - 100% of Vmax (%)	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.0	0.1

TD = total distance, < 20% Vmax (standing and walking), 20 - 50% Vmax (jogging), 51 - 80% Vmax (striding, HIR), 81 - 95% Vmax (sprinting) and 96 - 100% Vmax (maximum sprint). Vmax is based upon the percentage of each player's maximum running speed (Vmax) attained during any game played throughout the seasons.

4.3.3 Fifteen individual positions

Similar to the six positional groups, analysis demonstrated significant ($P < 0.0005$) variability across the individual positions for a number of the locomotive measures (see Table 4.3 - 4.5, see Appendices 4.14 – 4.16 for significant differences). The scrum half covered the greatest absolute distance during matches (~ 2.2 km more than the tighthead prop, which covered the least). With the exception of the fly half and inside centre positions, the scrum half travelled a significantly greater distance, relative to playing time, in comparison to all positions (74.2 $m{\cdot}min^{-1}$, 27% greater than the tighthead prop position; see Table 4.3-4.5), whilst predominantly travelling at speeds of less than 20% Vmax (39.5% of total distance) and 20-50% Vmax (45.5% of total distance), albeit not significantly differing from all positions. All three inside backs positions covered more relative distance (metres per minute) than the three outside backs, with the fly half covering the most (70 $m{\cdot}min^{-1}$). Similar, yet lower, relative distances were covered on average among the three outside backs positions, however no notable differences were evident across the backs positions, with the exclusion of the scrum half. Among the forwards, the three back row positions covered the most metres per minute with the openside flanker covering the greatest (64.3 $m{\cdot}min^{-1}$), which was comparable to the outside backs positions, as no substantial variability was evident.

The maximum speeds recorded for all the outside backs positions, particularly the two wing positions, were significantly higher than any other positions, the highest being achieved by the right wing (31.5 $km{\cdot}h^{-1}$), which was 31.8% greater than that of the slowest position, the right lock (23.5 $km{\cdot}h^{-1}$). However, the right wing (1.1%), and the fly half (1.2%) positions spent the greatest proportion of total distance at speeds of 81-95% Vmax ('sprinting) and 96-100% Vmax ('max sprinting'), albeit these equated to only 64.0 m and 70.2 m, respectively. More noteworthy was that the right wing and full back positions completed significantly more of their movements at speeds of less than 20% of Vmax ('standing and walking') and almost 50%, of their movements at speeds less than 20% of Vmax (‘standing and walking’), compared to 31% for the loosehead props. The hooker position was distinctive in that it spent the highest proportion of any position (53.4%) in the ‘jogging’ speed zone, yet the least (8.9%) in the ‘striding’ zone.

4.4 Discussion

As part of the largest study of its kind, our analysis of the movement patterns of elite level English Premiership rugby union players during competitive matches has revealed some marked differences between the forward and back positions, and further variation both within these positional groups and between individual player positions. Moreover, given the dearth of published quantitative statistics (using GPS) pertaining to rugby union players, it is anticipated that this data will contribute considerably to the knowledge base available to coaches and sports scientists, particularly within the English Premiership.

Consistent with previous research (Coughlan et al., 2011; Cunniffe et al., 2009; Deutsch et al., 2007, Duthie et al., 2005; Jones et al., 2015; Reid et al., 2013; Roberts et al., 2008) the backs in this sample covered greater absolute distances (6,134 m) than the forwards (5,221 m) during competitive matches. However, these distances were substantially lower than both the 7,002 m (backs) and 6,427 m (forwards) and 7,227 m (backs) and 6,680 m (forwards) reported in the case studies of Coughlan et al. (2011) and Cunniffe et al. (2009), respectively. In relative terms, English Premiership backs also covered more ground per minute (67.9 $m·min^{-1}$) than forwards (60.9 $m·min^{-1}$), albeit less than that recorded for the solitary back (74.0 $m·min^{-1}$) in Coughlan et al. (2011), and the back and forward position in Cunniffe et al. (2009) (71.9 $m·min^{-1}$ and 66.7 $m·min^{-1}$, respectively), yet similar to the findings of Jones et al. (2015) whose tighthead and loosehead forwards covered 60.7 and 60.8 $m·min^{-1}$, respectively, and between 65.6 and 69.1 $m·min^{-1}$ for the inside, outside and halfback positions.

Interestingly, the present data demonstrates that elite rugby union players cover greater absolute distances than rugby league players (McLellan et al., 2011b; Waldron et al., 2011b), although this might be explained by their spending more time on the pitch as their relative distances were substantially lower than rugby league backs (89 $m \cdot min^{-1}$) and forwards (95 $m \cdot min^{-1}$) (Waldron et al., 2011b). The greater relative measurements of rugby league players could be partly explained by the allowance of rolling substitutions, whilst the greater static components involved in rugby union could account for the lower relative distances found for rugby union players. Whilst not recorded in this investigation, a previous study (Roberts et al., 2008) has demonstrated that as much as 9.8 min of the game can be spent in static exertion alone.

The evidence that the least absolute and relative distances were covered by the front row and second row supports the common perception that their primary roles are to contest possession at set pieces and breakdowns (Deutsch et al., 2007; Eaton & George, 2006) and in doing so engage in more static activity, involving pushing and pulling actions, than that of the backs (Austin et al., 2011b; Docherty et al., 1988; Lacome, et al., 2014; Quarrie et al., 2013: Roberts et al., 2008). Lacome and colleagues (2014) suggested the lower maximal aerobic velocity recorded for the front row could possibly influence and be a limiting factor in distance covered, as it is typically associated with endurance quality, although recognised the need for further investigation to substantiate such claims. It is noteworthy that whilst the present findings were in accordance with Jones et al. (2015) they contradict those of Venter et al. (2011), who observed that front row players covered greater distances than the backs, however, their data were from under-19s players and based only on 60 minutes of a game. Among their sample of elite rugby union players, Roberts and colleagues (2008) reported the greatest distances were covered by the outside backs (6,190 m), which, as a group in the current study, covered the least distance of the three backs positional groups (5,919 m). This was in accordance with Austin et al. (2011b) and Lacome et al. (2014), where similarly, the outside back positions covered less distances (4,774 m, and 7,764 m, respectively) than the inside backs positions (6,095 m, and 8,079 m, correspondingly). Although, the recent findings of Jones et al. (2015) reported both absolute and relative distances were greater for the outside back positions, than the inside back positions, albeit not significantly. The greater distances reported by Roberts et al. (2008) for the outside back positions could be due to the different techniques (TMA and GPS) used within the two studies (Randers et al., 2010) even though similar methods were applied by Jones et al. (2015). It could perhaps, more pertinently, be that Roberts et al. (2008) analysed just 40 minutes of the game (between minutes 20 and 60) and normalised the data to represent a full match, causing the discrepancies, or the findings of Jones et al. (2015) are more reflective of the league the data were obtained from, further substantiating the need to identify the demands of the particular competition that players are taking part in. Further, substantial disparities are evident in the total distances covered across the studies, possibly owing to the differing methods used. For example, the total distances reported by Lacome et al. (2014) were based on players who participated in full matches only.

Anecdotally, the movements of the back row positions, particularly the two flanker positions, have often been regarded as being similar to the centre positions (Deutsch et al., 2007; Quarrie et al., 2013). Yet analysis of positional groups in the current findings suggests that the total distances covered by the back row positions are most comparable to the outside back positions. However, individual position analysis highlighted, in accordance with previous literature, the three individual back row positions across all speed classifications were most similar specifically to the inside centre position, with the only notable differences observed at speeds of walking.

Observations revealed the scrum half position characteristically covered both the most absolute distance, ~ 6.6 km per match, and significantly more metres per minute than the other five positional groups (74.2 $m \cdot min^{-1}$) and all individual playing positions with the exception of the fly half and inside centre. Whilst no statistical analysis were carried out on the individual positions data, Jones and colleagues (2015) also reported the scrum half position covered the greatest relative distances (71.7 $m \cdot min^{-1}$) in comparison to other positions, although only five GPS files were analysed. Given that the scrum half plays a pivotal role within rugby union, acting as the link between the forwards and backs, this is not surprising. Typically, they are required to keep pace with numerous patterns of play in order to produce the ball accurately and quickly to the backs, often following contests by the forwards, to obtain or maintain possession (Bompa & Claro, 2009) and as such, greater distances can be expected.

As reported in Chapter 3 of this thesis, previous analyses of the intensity of players' movements (or 'workload') in team sports have tended to quantify the distances covered within arbitrary predetermined absolute speed categories or zones (Coughlan et al., 2011: Cunniffe et al., 2009; Rampinini et al., 2007a; Roberts et al., 2008). However, the findings in Chapter 3 and the results in the present chapter demonstrate that the peak match speeds attainable by the backs are generally higher than those of the forwards. This means that for certain forward players, the distances moved in the 'sprinting' zone are likely to be less than back players because in absolute terms, their ability to reach such high speeds is limited, and in this way their intensity profiles will be mis-represented. Hence, employing relative speed classifications to the current data (based upon individual maximum sprint speeds achieved during matches played, in the manner of Venter et al., 2011) is more reasonable. As a consequence, it emerged that English Premiership matches were typically played at low speeds, with all positions covering at least 80% of their total distances at either < 20% Vmax (standing/walking) or 20 – 50% Vmax (jogging) pace, which is in alignment with previous findings where between 88% - 95% of match time was spent in low intensity movements (Cunniffe et al., 2009; Jones et al., 2015; Roberts et al., 2008). Markedly, all the back positions covered greater distances walking than the forwards, with all the three outside backs positions (full back, right wing and left wing) covering significantly greater distances at this intensity. Such a statistic probably reflects the backs' frequent pursuit of open space (Bompa & Claro, 2009) and continual repositioning in anticipation of receiving the ball.

The average distances covered in the two sprinting categories (> 81% Vmax) were very low for players in all positions of play, with a spread of only 58.0 m between the lowest (hooker; 11.7 m, 0.3%) and the highest (fly half; 70.2 m, 1.2%). Collectively, the forwards averaged 232.7 m sprinting, whereas backs averaged 312.0 m. Indeed, only one individual position (fly half) covered any distance at 'maximum sprint' speed (96 – 100% Vmax). When relative measures were analysed the outside back positions were found to cover a greater percentage of distance whilst sprinting, in line with previous findings (Coughlan et al., 2011; Cunniffe et al., 2009; Deutsch et al., 1998; Deutsch et al., 2007; Duthie et al., 2005; Roberts et al., 2008). However, large differences were evident in the distances observed relative to previous findings, with Cunniffe and colleagues (2009) reporting backs to sprint ~ 524 m and forwards ~ 313 m per match, Roberts et al. (2008) ~ 164 m for the forwards and ~ 207 m for the backs and Jones et al. (2015) reporting between 226 – 392 m for the back positions and ranging between 65 - 166 m for the forward positions. Clearly, the backs in the current investigation covered approximately five times less distance sprinting than reported by Cunniffe et al. and two times less distance than Roberts et al. However, such discrepancies could primarily be owing to the selection of the speed classifications, as Chapter 3 revealed the application of the thresholds outlined by Roberts et al. (2008) and Cunniffe et al. (2009) may exhibit differences in sprint distances of between ~ 104 - 350 m, respectively for positional groups. It could be that the backs analysed by Cunniffe and colleagues (2009) may have covered only twice as much distance sprinting and not five times as much, considering ~ 350 m could be owing to the threshold employed. Likewise, distances observed by Roberts and co-authors (2008) might have been similar to the current study when considering up to ~ 104 m difference might be accounted for by the speed threshold used.

Nonetheless, the present findings also illustrated within group variances, notably that the outside backs covered a greater percentage of distance at this speed (sprinting, > 81% Vmax) compared to the front and second row and the scrum half position, yet not compared to the inside backs or the back row. Indeed, no notable differences were present between the inside backs and any of the forward positions, but they were evident between the inside, outside back and the back row with the scrum half. Of the back row positions, whilst not significant, the findings suggest the blindside and openside flanker positions cover greater percentage of distances in this speed zone (sprinting, > 81% Vmax) compared to the number 8 position. This inconsistency with previous work (Eaton & George, 2006; Quarrie et al., 2013; Roberts et al., 2008) could be due to the lack of analysis on individual positions or the lower maximum speeds of the forwards not being accommodated by the absolute (rather than relative) nature of the speed classification used in the above studies. If, for example, the same sprinting speed classifications were applied to the current data, it would have emerged that some of the forward positions (tighthead prop, loosehead prop and right lock) had not engaged in any sprinting during a match, when in fact, using the relative measure, they sprinted similar distances to a number of positions. Similarly, Lacome et al. (2014) reported mean accelerations at ‘high intensities’ were greatest in the forwards, particularly the back row positions as opposed to the back positions, when individual physiological measurements were used to determine velocity intensity levels.

4.5 Practical Applications

The information provided in this chapter could prove vital for practitioners to help in designing position-specific training programmes for teams competing in the English Premiership. These findings can be utilised to adapt and modify training to enhance its specificity per individual position. In the main, conditioning programmes should elicit training adaptations to enable the back positions as a group (although particularly the scrum half and fly half positions), to cope with greater locomotive demands during match play (typically 74 - 70 $m \cdot min^{-1}$). Whilst the findings suggest locomotive demands of the forwards positions, mostly the prop and lock positions are less arduous in terms of distances (ranging between 58 – 63 $m \cdot min^{-1}$) intensity at which the forwards positions are required to participate at are higher than the backs. Although few differences were evident across positions for distances travelled at “HIR” speeds (> 51% Vmax) (the average ranging between 700 – 1,000 m), the forwards were identified to cover over 50% of total distances at speeds of “jogging” (21-50% Vmax) opposed to ~50% at speeds of “walking” for the backs (<20% Vmax) (with the exception of the scrum half, fly half and inside centre). Therefore conditioning programmes should replicate such distances and intensities to imitate match demands as closely as possible. In addition, practitioners should pay attention to the development of speed, particularly for the outside back positions (although not exclusively), as characteristically it is necessary to reach speeds of up to 36 $km \cdot h^{-1}$ during match play. Therefore, speed training should be incorporated into training programmes to ensure sessions frequently elicit the speeds required to be competitive within the English Premiership. Aside from helping to inform training, the analysis of within this chapter could assist in devising return to play protocols following injury. It could be used as a comparable measurement for practitioners to determine whether players are able to equal, if not exceed, their individual positional match demands, and therefore their readiness to play competitively.

4.6 Summary

In conclusion, this investigation, which is the first to quantify the movement characteristics of positional groups and all 15 individual positions of elite rugby union players participating in the English Premiership using GPS, has highlighted notable variations that practitioners/coaches should be mindful of when implementing training programmes. The findings concur with earlier research that the game is predominantly played at low speeds interspersed with relatively few instances of sprint running. The backs were found to cover greater distances than the forwards, with the scrum half covering the most. Further, the use of individual maximum speed (Vmax) in determining speed classifications provided new insight into the position-related sprinting demands of the game at this standard. For instance, that there were few significant differences in total distances covered when sprinting between the forward and the back positions. Whilst the predominantly aerobic nature of rugby union, interspersed with anaerobic spurts, justifies the current form of analysis, considering the multidimensional nature of the game, presenting the locomotive movement demands alone only provide a partial analysis of the match demands. Indeed, in order to fulfil the aims of the thesis, to provide a comprehensive analysis of elite rugby union in the English Premiership, further examination of the performance-related aspects of match play, such as the more static and/or impact-related exertions, in addition to the ball handling efforts (for instance passes, ball carries, kicking), are required to determine a more extensive analysis of match demands and the associated physical loads placed on the body.

Chapter 5: Performance Analysis of Elite Level English Premiership Rugby Union Players

5.1 Introduction

Global positioning systems (GPS), time-motion, and notational analysis have been utilised to provide rugby union practitioners, sports scientists and coaches with important information on the demands of the game from its pre- to current professional status (Austin et al., 2011a; Austin et al., 2011b: Deutsch et al., 2007; Duthie et al., 2003; Duthie et al., 2005; Eaton & George, 2006; Lacome et al., 2014; Quarrie et al., 2013; Roberts et al., 2008). Primarily, research has focused on the movement demands throughout match play to help design appropriate training programmes. However, as rugby union is a game comprising both running actions and performance-related skills, including contact elements such as tackling, scrummaging, rucking, mauling, static exertions, passing, kicking and catching (Duthie et al., 2003), the quantification of movement characteristics alone does not provide an adequately detailed analysis of the physical demands of the game. In recognising this, the performance-related elements of rugby union and its key performance indicators (KPIs) need to be considered.

To-date, relatively little attention has been paid to position-related performance indicators, and consequently the development of performance profiles, particularly at the professional club level (Hughes et al., 2012; James et al., 2005; Parsons & Hughes, 2001; Quarrie et al., 2013; Vivian et al., 2001). In the most extensive analysis to-date, the study of Quarrie et al. (2013) involving 763 international rugby union players over the course of 90 matches identified that significant positional demands/actions were present at the international standard. The back row players were reported to perform the most number of tackles per match (averaging 14), whereas the outside backs and props the least. The flankers and back rows were also found to be penalised the most, committing the highest number of penalties, typically one per match. Moreover, Quarrie et al. (2013) illustrated that centres and wingers scored considerably more tries than any other position. Interestingly, the work of Quarrie et al. (2013) suggested notable differences existed between the international standard and the lower level (club) professional game, particularly in the assessment of movement characteristics. For example, they observed that international players travelled greater distances at higher intensities when compared to the professional club level (Eaton & George, 2006; Roberts et al., 2008) and less at lower intensities than professional clubs players, echoing findings in soccer (Mohr et al., 2003).

James and colleagues (2005) are one of the few research groups who have attempted to profile performance-related efforts across playing positions in elite club level rugby union players. Their findings identified that the flankers performed the highest frequency of tackles, along-side the scrum half position, averaging ~ 10 per match (which is less than at the international standard). Moreover, James and colleagues (2005) reported the scrum halves carried the ball significantly more often than any other position (~ 10 per match), and, in contrast to Quarrie et al. (2013), that the number of tries scored across positions was similar. However, the findings of James et al. (2005) are limited by the sample size used; 22 players over 21 matches. In addition, whilst James et al. (2005) endeavoured to develop individual performance profiles, the number of athletes analysed per playing position ranged between one and five, and large variations within positions were reported to exist. Evidently, this is insufficient data to provide a fair representation of performance-related positional demands at the professional club level, and further investigation is warranted to enable the development of positional (group or individual) playing profiles. Furthermore, it is believed that an understanding of the typical performances required to be competitive within a particular standard (league) is essential in order to gain a greater appreciation of what is 'crucial' to succeed, and consequently for optimal preparation (Hughes & Bartlett, 2002). Whilst Chapter 4 has provided representative data on the locomotive movement demands at the elite

(English) club level, the aim of this investigation was to utilise video analysis of English Premiership rugby union matches to quantify the position-specific performance-related demands over three seasons of competition.

5.2 Methods

5.2.1 Participants

A total of 524 GPS files (261 home games, 245 away games and 18 games played on neutral grounds) were analysed from 149 players participating in regular season matches in the English Premiership from 2010-2013. Further details on participants are as described in Chapter 4.2.1 (p. 137)

5.2.2 Procedures

All the matches took place between September 2010 and May 2013 on a Friday, Saturday or Sunday and were played on 15 different grounds used by the participating English clubs. The matches were recorded with a Sony video camera at a frame rate of 25 Hz at all 15 grounds. Each match was filmed from an elevated platform and positioned perpendicular to the pitch, on or as close to the halfway-line as possible. For each match in which players had worn GPS devices (and thereby provided locomotive data, as reported procedures in Chapter 4.2.2, p. 137), the corresponding video footage was provided for performance analysis by PGIR (an analysis franchise for the England Rugby Football Union) via a secure remote network server made available from the company. Additionally, OPTA statistics and codes were also made available via PGIR, providing information on all players' and teams' performances (including number of set pieces and the area of the pitch, possession, passes, ball carries, kicks, tackles, missed tackles, penalties and turnovers). The codes were later edited and adapted as required by an analyst (the present researcher who has seven years' experience at the professional level) through the use of SportsCode software (Sportstec, Lower Hutt, New Zealand). These codes were later exported to Microsoft Excel (Microsoft Corporation, USA) for each individual player to allow further analysis.

A note of the time (Greenwich Mean Time) at the beginning and end of each match was made and subsequently the GPS raw data were exported into Microsoft Excel (Microsoft Corporation, USA) to enable manual synchronisation of the GPS raw data and the performance related data obtained from the video footage via the time stamp. This enabled movement classifications to be combined with the performance elements of match play post-data collection. If a player was substituted, a note of the match time was taken, enabling subsequent calculations of the length of time spent on the pitch by each player. The timing of substitutions across the whole Premiership season was provided by the RFU and used to determine the average substitution time per position. A player was only included in the study if he had spent time on the pitch greater than or equal to the average substitution time for his playing position. Accordingly, 524 GPS files were subsequently analysed from 149 players. The raw GPS and video files were later segmented into full match, first and second halves and then exported from Microsoft Excel (Microsoft Corporation, USA), to SPSS (version 21) for statistical analyses.

5.2.3 Player groupings

The players were grouped using three different classification systems. Firstly as either a forward or a back, secondly, as one of six positional groups, with the scrum halves assigned a category of their own, and thirdly by their individual positions. For further details see Chapter 4.2.3 (pp.138)

5.2.4 Key Performance Indicators (KPIs)

The selection of 18 performance indicators (Table 5.1) which were perceived as both important and useful for practitioners were selected based on the knowledge of the performance analyst (the current author, who has worked at the professional club and international standard for a total of seven years), professional level coaches and practitioners (working in English premiership clubs and at the international standard) and on previously available literature (Austin et al., 2011b; Eaves, Hughes & Lamb, 2005; James et al., 2005; Jones et al., 2004; Lim et al., 2009; Roberts et al., 2008; Quarrie et al., 2013; IRB Laws 2013). The KPIs were reported both as a total frequency of events (Table 5.1) and as a percentage of total team events (where possible) (Table 5.2) per position. Intra-observer reliability was conducted by the lead researcher using Cohen's Kappa method. A purpose-built coding template was used to analyse 40 minutes of an elite level rugby union game to determine the reliability of identifying individual players and their actions. This process was repeated 6 weeks after the initial coding took place to reduce any learning effect, and compared to the original findings. The results illustrated acceptable intra-reliability was evident for the player and action identification (97% and 95% agreement and Kappa values of 0.96 and 0.93, respectively), although the intra-reliability was less agreeable for the player arrival number to the ruck (Kappa value of 0.66) and the indicator was subsequently eliminated from further analysis.

Table 5.1 Key performance indicators (KPIs).

Indicator	Definition
Ball Carries	Total number of player ball carries
Ball Carries into Contact	Total number of player ball carries into the opposition defensive line
Ball Carries &Try scored	Total number of player ball carries ending in a try being scored
Passes	Total number of player passes. A pass is to transfer a ball to a team mate by throwing it
Kicks	Total number of player kicks, including kicks in-field, to touch, drop goals, and kicks at goal
Tackles Made	Total number of player tackles made. “A tackle occurred when the ball carrier was held by one or more opponents and was brought to ground” (IRB LAWS 2003)
Tackles Missed	Total number of missed tackles. “A missed tackle occurred when a player attempted to make a tackle but the ball carrier was not brought to ground” (IRB LAWS 2003)
Total Rucks	Total number of player rucks. “A ruck is a phase of play where one or more players from each team, who are on their feet, in physical contact, close around the ball on the ground and open play has ended. A player was involved in a ruck when they attended a ruck and used their feet to try to win or keep possession of the ball, without being guilty of foul pay” (IRB LAWS 2003)
Contested Rucks	A contested ruck was determined subjectively when a player performed visible static exertions and contested for the ball whilst in the ruck
Total Scrum	Total number of scrum involvements
Own Lineout Lifter	Total number of player lineout lifts of team mate on own team’s lineouts
Total Scrum	Total number of scrum involvements
Own Lineout Lifter	Total number of player lineout lifts of team mate on own team’s lineouts
Own Lineout Caught	Total number of player lineout catches on own team’s lineouts
Static Exertions	Total number of static exertions including scrums, contested rucks, mauls, and tackles
Static Exertions Duration	Total player time spent in static exertions
% of Ball in Play in Static Exertion	Total percentage of ball in play time (whilst on the pitch) spent in static exertions
High Intensity Exercise Bouts (HIEB)	Total high intensity exercise bouts included a combination of static exertions (scrums, contested rucks, counter rucks, mauls, or tackles), lineout lifts or maximum sprints in succession with 21seconds or less between each effort. Each HIEB effort was determined manually via the raw exported data in Microsoft excel. A maximum sprint as > 81% Vmax speed

[1]According to Gabbett (2012); [2]Adapted from Spencer et al. (2004), Eaton and George (2006), and Gabbett et al. (2012).

Table 5.2 Relative occurrence of key performance indicators.

Indicators	Definition
Ball Carries	Percentage of total team ball carries a player was involved in
Ball Carries into Contact	Percentage of total individual ball carries that the player carried the ball into the opposition defensive line
Ball Carries & Try scored	Percentage of total team ball carries that the player carried and scored a try
Passes	Total player passes as a percentage of total team passes
Kicks	Total Player kicks as a percentage of total team kicks
Tackles Made	Total player tackles as a percentage of total team tackles made
Tackles Missed	Total player missed tackles as a percentage of total team missed tackles
Total Rucks	Total rucks attended as a percentage of total team rucks
Contested Rucks	Percentage of total rucks where the player performed static exertion and contested for the ball
Turnover Lost	Total player turnovers as a percentage of total team turnovers
Penalty Conceded	Total player penalties conceded as a percentage of total team penalties
Own Lineout Caught	Player lineout catch as a percentage of total own lineouts
Own Lineout Lifter	Player lineout lifter as a percentage of total own lineouts

5.2.5 Statistical Analyses

Initially, diagnostic tests (Shapiro-Wilk and Levene) were performed on the distributions of all the dependent variables (KPIs) to check the assumptions of normality and homogeneity of variance. As most did not satisfy these conditions, non-parametric Mann-Whitney and Kruskal-Wallis hypothesis tests were used to compare the variables between forwards and backs, the six pre-defined positional groups and the 15 individual positional groups, respectively. Descriptive statistics were represented by the median and inter-quartile range (IQR). Where appropriate, *post-hoc* Mann-Whitney tests were used to isolate significant differences between specific pairs of groups. Bonferroni adjustments to the alpha were applied to offset the increased risk of a type I error that occurs when conducting multiple comparisons.

5.3 Results

5.3.1 Forward and Back positional groups

Notable differences in the performance indicators were displayed between the forwards and backs (Tables 5.3 and 5.4). The forwards were involved in more static exertions than backs (41.0 versus 11.0) and spent a significantly ($P < 0.05$) greater percentage of ball in play time in such exertions (14.1% versus 0.9%). Substantial differences were evident in the frequency of rucks attended (forwards 21.0 and backs 7.0) and the frequency of contested rucks (15.0 for forwards and 5.0 for backs), albeit the backs contested 75.0% of the rucks they were involved in compared to 70.0% for the forwards. Significant differences ($P < 0.05$) were present in the frequency of tackles made (9.0 and 6.0 for forwards and backs, respectively) with the forwards responsible for 10.3% of total team tackles. The forwards (2.0) were involved in double the amount of high intensity exercise bouts than the backs, albeit this difference was small. Although the back positions were involved in a greater number of attacking performance indicators (including total frequency of passes, ball carries and kicks) and carried and passed the ball significantly more times than the forwards (6.0 and 4.0 versus 4.0 and 1.0, correspondingly) they were also accountable for a greater number of turnovers lost (1.0 versus 0.0, respectively) and percentage of team turnovers lost (8.3% versus 0.0%).

Table 5.3 Average (median) frequencies of KPIs for forward and back positions.

Indicator	Forwards (n=246)	IQR	Backs (n=278)	IQR
Ball Carries	4.0	5.0	6.0*	4.0
Ball Carries into contact	4.0	4.0	5.0	4.0
Ball Carries &Try scored	0.0	0.0	0.0*	0.0
Passes	1.0	2.0	4.0*	6.0
Kicks	0.0	0.0	1.0*	4.0
Tackles Made	9.0	6.0	6.0*	4.3
Tackles Missed	0.0	1.0	0.0	1.0
Total Rucks	21.0	0.0	7.0*	0.0
Contested Rucks	15.0	8.0	5.0*	5.0
Turnover Lost	0.0	1.0	1.0*	2.0
Penalty Conceded	0.0	1.0	0.0*	0.0
Total Scrum	14.0	6.0	0.0*	0.0
Own Lineout Lifter	2.0	5.0	0.0*	0.0
Own Lineout Caught	1.0	3.3	0.0*	0.0
Static Exertions	41.0	12.0	11.0*	7.0
Static Exertions Duration (s)	320.1	118.6	35.5*	36.0
% of Ball in Play in Static Exertion	14.1	5.3	0.9*	0.9
High Intensity Exercise Bouts (HIEB)	2.0	2.0	0.0*	0.0

*Denotes significantly different from forward positions

Table 5.4 Average (median) percentage of total team key performance indicators for forwards and backs.

Indicator	Forwards (*n*= 246)	IQR	Backs (*n*=278)	IQR
Ball Carries	4.8	4.2	6.5*	4.7
Ball Carries & Try scored	0.0	0.0	0.0*	0.0
Passes	1.2	2.2	3.4*	5.0
Kicks	0.0	0.0	4.4*	13.8
Tackles Made	10.3	6.2	6.1*	5.2
Tackles Missed	0.0	11.1	0.0	11.1
Total Rucks	30.3	13.1	28.7*	8.3
Contested Rucks	70.0	20.5	75.0*	33.3
Turnover Lost	0.0	7.3	8.3*	12.7
Penalty Conceded	0.0	6.0	0.0*	0.0
Own Lineout Caught	7.1	28.0	0.0*	0.0
Own Lineout Lifter	17.7	37.7	0.0*	0.0

*Denotes significantly different from forward position

5.3.2 Six positional groups

Analysis revealed significant ($P < 0.003$) differences between positional groups for numerous performance indicators (see Tables 5.5 and 5.6. see Appendices 4.17 and 4.18 for significant differences). All three forward groups were involved in significantly greater static exertions than the back groups, with the back row the most (45.0) and the scrum half the least (6.0). Both the back row and second row (43.0) were involved in significantly more static exertions than the front row (37.0) position, though when expressed in relative terms (% of ball in play), this was not the case. There were no marked variances in total rucks within the forward positional groups, ranging between 22.0 (second row), 21.0 (front row) and 21.0 (back row). Overall, all forward positions participated in more than a quarter (~ 26 – 27%) of total team rucks. The back row position was distinctive in that it performed a significantly higher frequency of tackles (12.0) than both the front (8.0) and second row (8.0) positions, and indeed any other positional group. Characteristically, the back row players executed most high intensity exercise exertions (3.0), again markedly more than the front (1.0) and second row (2.0), the scrum half (0.0) and inside and outside backs (0.0). Among the backs, the inside backs were distinctive in that they had substantially greater participation in static exertions (14.0) compared to both the outside backs (9.0) and scrum half (6.0) positions, although the inside and outside backs spent (similar) proportions of ball in play time in static exertions that were significantly higher than that of the scrum half position. Distinguishably, the inside backs performed significantly more tackles (8.0) and a higher percentage of total team tackles (8.3%) than both the scrum half (4.6%) and outside back (3.8%) positions, equalling the frequency of tackles reported for both the front and second rows (8.0 and 8.0, respectively). The scrum half position was involved in significantly less total rucks (2.0) and percentage of total rucks (2.0%) than any other positional group, but was unique in its frequency of passes throughout match play, distributing over 50% (50.9) of all team passes.

In terms of ball carries, the front row carried the ball (3.0) significantly less than all other positional groups except the scrum half position. The outside backs carried the ball the most (7.0), both absolutely and relative to the percentage of total team ball carries (7.2), but interestingly, the number of carries by two of the forward groups (the second and back row positions) was not significantly different to any of the three back positions.

Table 5.5 Average (median) frequencies of KPIs for six positional groups.

Indicator	Front Row (*n*=93)	IQR	Second Row (*n*=69)	IQR	Back Row (*n*=84)	IQR	Scrum Half (*n*=36)	IQR	Inside Backs (*n*=126)	IQR	Outside Backs (*n*=116)	IQR
Ball Carries	3.0	3.0	5.0	3.5	5.0	4.8	3.5	2.5	6.0	5.0	7.0	4.0
Ball Carries into contact	3.0	3.0	4.0	3.0	4.5	4.0	2.0	2.0	5.0	5.0	6.0	4.0
Ball Carries &Try scored	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Passes	1.0	2.0	2.0	2.0	1.0	1.8	51.5	15.0	4.0	5.0	3.0	3.0
Kicks	0.0	0.0	0.0	0.0	0.0	0.0	5.0	5.0	0.0	2.0	1.0	2.0
Tackles Made	8.0	4.0	8.0	6.0	12.0	6.8	5.0	3.0	8.0	4.0	4.0	4.0
Tackles Missed	0.0	1.0	0.0	1.0	0.0	1.0	1.0	1.0	1.0	1.3	0.0	1.0
Total Rucks	21.0	9.0	22.0	12.0	21.0	10.0	2.0	2.0	9.0	6.0	7.0	5.8
Contested Rucks	14.0	8.5	14.0	7.5	16.0	8.8	2.0	2.0	6.0	5.0	5.0	4.0
Turnover Lost	0.0	0.0	0.0	1.0	0.0	1.0	1.0	2.0	1.0	2.0	1.0	1.8
Penalty Conceded	0.0	1.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Scrum	13.0	4.0	15.0	6.5	15.0	5.0	0.0	0.0	0.0	0.0	0.0	0.0
Own Lineout Lifter	2.0	5.0	3.0	5.0	2.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0
Own Lineout Caught	0.0	6.5	2.0	4.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0
Static Exertions	37.0	10.5	43.0	13.0	45.0	11.8	6.0	4.0	14.0	6.3	9.0	5.0
Static Exertions Duration	307.1	98.0	336.1	137.1	322.6	116.8	10.5	13.0	46.0	33.3	34.5	0.0
% of Ball in Play in Static Exertion	14.1	5.3	14.7	4.6	13.6	6.2	0.3	0.4	1.1	1.8	0.9	0.8
High Intensity Exercise Bouts (HIEB)	1.0	1.0	2.0	2.0	3.0	3.0	0.0	0.0	0.0	1.0	0.0	0.0

Table 5.6 Average (median) percentage of total team performance efforts for six positional groups.

Indicator	Front Row (*n*=93)	IQR	Second Row (*n*=69)	IQR	Back Row (*n*=84)	IQR	Scrum Half (*n*=36)	IQR	Inside Backs (*n*=126)	IQR	Outside Backs (*n*=116)	IQR
Ball Carries	3.8	3.9	5.3	3.3	5.3	4.8	4.2	2.3	6.9	4.4	7.2	4.9
Ball Carries & Try scored	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Passes	0.9	1.8	1.6	2.0	1.4	1.5	50.9	11.4	3.7	4.5	2.7	2.4
Kicks	0.0	0.0	0.0	0.0	0.0	0.0	18.9	16.6	0.0	7.6	4.6	10.5
Tackles Made	8.4	5.1	9.5	5.5	12.4	5.7	4.6	2.7	8.3	4.6	3.8	3.9
Tackles Missed	0.0	10.6	0.0	11.1	0.0	11.1	7.7	14.3	6.3	13.3	0.0	9.1
Total Rucks	26.9	11.4	26.6	11.4	28.0	11.4	2.0	11.4	10.9	11.4	8.3	11.4
Contested Rucks	66.7	21.4	70.0	20.0	76.7	19.5	100.0	0.0	75.0	26.2	75.0	23.4
Turnover Lost	0.0	0.0	0.0	6.9	0.0	9.1	8.0	13.7	8.3	12.5	8.3	13.3
Penalty Conceded	0.0	6.7	0.0	0.0	0.0	6.3	0.0	0.0	0.0	0.0	0.0	0.0
Own Lineout Caught	0.0	66.7	17.7	28.9	5.9	12.5	0.0	0.0	0.0	0.0	0.0	0.0
Own Lineout Lifter	17.7	40.0	30.8	33.5	12.9	25.0	0.0	0.0	0.0	0.0	0.0	0.0

5.3.3 Fifteen individual positional groups

Similar to the six positional groups, analysis demonstrated significant ($P < 0.0005$) variability across the individual positions for numerous KPIs (see Tables 5.7 - 5.12. see Appendices 4.19 – 4.24 for significant differences). The left lock was involved in the highest frequency of static exertions during matches (49.5), more than the right lock (40.0) and considerably more than the scrum half, who engaged in the least (6.0). Moreover, the left lock also spent the greatest percentage of ball in play time in static exertions (15.8), although not significantly more than any other forward positions. In terms of total rucks, the left lock attended the most across all positions (27.0), typically participating in 34.1% of total team rucks, and significantly more than the right lock (20.0 and 24.2%, respectively). Of the rucks attended, the left lock players contested 66.0%, which was less than all three back row positions; blindside flanker (77.8%), openside flanker (74.5%) and the number 8 position (78.2%). The tighthead prop, whilst attending a similar number of total rucks (21.0) to the other forward positions, contested significantly less rucks (52.9).

The back row positions were typified by several performance indicators. For example, the blindside and openside flankers tended to be involved in the most number of tackles throughout matches, typically about 12 tackles per match, representing ~ 13.6% of total team tackles, which was substantially higher than the corresponding figures for the loosehead and tighthead prop positions and the three outside backs groups. The back row players, particularly the openside flanker (3.0) and number 8 positions (3.0), also participated in the most high intensity exercise bouts. The inside and outside centres engaged in the most static exertions (15.0 and 14.0, correspondingly), and spent a significantly greater proportion of ball in play time in static exertions than any of the fly half, left wing and the scrum half positions. The back positions were characteristically involved in fewer rucks and percentage of total rucks during match play, yet of those they attended, in the main they contested a larger percentage (69.2 – 100%) than the forward positions. The scrum half and the outside back positions were responsible for the lowest percentage of total team tackles during matches, and the scrum half the greatest percentage of total team missed tackles (7.7%). The inside centre and fly half positions made significantly more tackles than both the scrum half and outside backs, though similar amounts to those of the front and second row groups (Table 5.7-5.9).

Full back players typically carried the ball more often than any other back positions during match play (8.0), and significantly ($P < 0.0005$) more than all the forward positions (with the exception of the number 8 position) and both the scrum and fly half. Of note, the number 8 position typically carried the ball the most of all positions (10.5 per match), representing 13.6% of total team ball carries. However statistical differences were only evident between the three front row positions and the scrum half position for the absolute total ball carries. Moreover, no significant difference in the frequency of tries between positions was observed (with the exception of the left wing and the loosehead prop). Finally, and unsurprisingly, scrum half and fly half positions were distinctive for their handling of the ball and kicking. Between these two positions, they accounted for more than 68% of total team passes and 74% of the total ball kicking, considerably greater than any other individual position.

Table 5.7 Average (median) frequencies of key performance indicators for individual positions (1 – 5).

Indicator	Loosehead Prop (1) (*n*=30)	IQR	Hooker (2) (*n*=32)	IQR	Tighthead Prop (3) (*n*=31)	IQR	Left Lock (4) (*n*=24)	IQR	Right Lock (5) (*n*=45)	IQR
Ball Carries	3.0	4.0	4.0	3.0	3.0	4.0	5.0	2.8	5.0	4.0
Ball Carries into contact	3.0	4.3	3.0	3.0	2.0	3.0	4.0	2.8	5.0	3.5
Ball Carries &Try scored	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Passes	1.0	1.3	1.0	1.8	1.0	2.0	2.0	2.0	2.0	2.5
Kicks	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Tackles Made	7.0	0.7	10.0	0.7	6.0	0.9	9.0	0.5	8.0	0.9
Tackles Missed	0.0	1.0	1.0	1.0	0.0	1.0	0.5	1.0	0.0	1.0
Total Rucks	21.0	11.3	21.0	7.8	21.0	8.0	27.0	8.3	20.0	9.5
Contested Rucks	15.0	10.3	14.5	7.8	12.0	6.0	17.0	8.5	14.0	8.0
Turnover Lost	0.0	0.0	0.0	1.0	0.0	0.0	0.0	1.0	0.0	1.0
Penalty Conceded	0.0	1.0	0.0	0.0	0.0	1.0	0.0	1.0	0.0	0.0
Total Scrum	13.5	5.3	13.0	4.8	13.0	4.0	18.0	5.8	13.0	6.0
Own Lineout Lifter	5.0	5.3	0.0	0.0	3.0	2.0	4.5	3.0	3.0	4.0
Own Lineout Caught	0.0	0.0	0.0	0.0	0.0	0.0	1.5	3.5	3.0	4.5
Static Exertions	39.0	14.3	39.0	7.8	35.0	7.0	49.5	13.5	40.0	12.5
Static Exertions Duration (s)	318.6	94.1	321.6	106.0	295.1	95.0	382.6	109.6	305.1	127.6
% of Ball in Play in Static Exertion	14.2	5.4	13.9	6.6	14.1	4.4	15.8	5.5	14.3	6.8
High Intensity Exercise Bouts (HIEB)	2.0	3.0	1.0	1.0	1.0	2.0	2.0	2.0	2.0	1.0

Table 5.8 Average (median) frequencies of key performance indicators for individual positions (6 – 10).

Indicator	Blindside Flanker (6) (*n*=30)	IQR	Openside Flanker (7) (*n*=42)	IQR	Number 8 (8) (*n*=12)	IQR	Scrum Half (9) (*n*=36)	IQR	Fly Half (10) (*n*=24)	IQR
Ball Carries	4.5	4.3	5.0	5.0	10.5	9.0	3.5	2.5	5.0	3.8
Ball Carries into contact	4.0	3.3	4.5	4.3	9.0	8.0	2.0	2.0	4.0	3.5
Ball Carries &Try scored	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Passes	1.0	1.3	1.0	1.3	2.0	3.5	51.5	15.0	19.0	10.3
Kicks	0.0	0.0	0.0	0.0	0.0	0.0	5.0	5.0	13.5	13.5
Tackles Made	12.0	1.1	12.0	0.6	8.5	1.0	5.0	0.9	9.0	0.7
Tackles Missed	1.0	1.0	0.0	1.0	0.0	1.0	1.0	1.0	1.0	2.0
Total Rucks	19.0	9.8	23.0	10.3	16.0	10.8	2.0	2.0	4.5	5.0
Contested Rucks	15.0	8.3	16.0	10.0	13.0	6.5	2.0	2.0	4.0	4.0
Turnover Lost	0.0	1.0	0.5	1.0	1.0	1.0	1.0	2.0	1.0	1.0
Penalty Conceded	0.0	0.0	0.0	1.0	0.0	1.0	0.0	0.0	0.0	0.0
Total Scrum	15.0	4.5	13.5	4.5	15.5	4.0	0.0	0.0	0.0	0.0
Own Lineout Lifter	2.0	5.0	1.0	3.0	1.0	2.0	0.0	0.0	0.0	0.0
Own Lineout Caught	1.0	3.0	0.0	1.0	0.0	1.0	0.0	0.0	0.0	0.0
Static Exertions	48.0	13.8	46.0	12.5	41.0	7.0	6.0	4.0	12.5	5.8
Static Exertions Duration (s)	351.1	153.3	317.6	122.6	289.1	74.1	10.5	13.0	25.5	33.3
% of Ball in Play in Static Exertion	14.8	6.5	13.3	4.2	11.5	0.4	0.3	0.8	0.6	1.9
High Intensity Exercise Bouts (HIEB)	2.0	2.0	3.0	2.0	3.0	2.0	0.0	0.0	0.0	0.0

Table 5.9 Average frequencies of key performance indicators for individual positions (11 – 15).

Indicator	Left Wing (11) (*n*=40)	IQR	Inside Centre (12) (*n*=37)	IQR	Outside Centre (13) (*n*=65)	IQR	Right Wing (14) (*n*=42)	IQR	Full Back (15) (*n*=34)	IQR
Ball Carries	6.0	3.8	7.0	3.5	6.0	5.0	6.0	5.0	8.0	4.0
Ball Carries into contact	6.0	4.0	6.0	4.5	5.0	5.0	4.5	4.3	7.0	5.0
Ball Carries &Try scored	0.0	1.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0
Passes	1.5	3.0	4.0	4.0	3.0	2.5	3.0	3.0	4.0	2.5
Kicks	1.0	1.0	0.0	1.0	0.0	1.0	1.0	1.3	4.0	5.0
Tackles Made	5.0	0.6	9.0	7.2	7.0	5.5	4.0	7.6	3.0	8.3
Tackles Missed	0.0	1.0	1.0	1.5	0.0	1.0	0.0	1.0	0.0	0.3
Total Rucks	8.0	6.0	10.0	5.5	9.0	6.5	6.0	5.0	7.5	5.3
Contested Rucks	6.0	5.0	7.0	4.0	7.0	5.0	5.0	4.3	5.0	3.0
Turnover Lost	1.0	1.0	1.0	2.0	1.0	2.0	1.0	2.0	1.0	2.0
Penalty Conceded	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Scrum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Own Lineout Lifter	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Own Lineout Caught	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Static Exertions	10.5	6.0	15.0	5.5	14.0	6.0	8.0	5.3	8.0	4.0
Static Exertions Duration	43.5	37.8	49.0	29.5	48.0	28.0	27.5	28.2	39.5	30.5
% of Ball in Play in Static Exertion	1.2	1.7	1.2	1.8	1.2	0.7	0.7	0.8	1.0	3.0
High Intensity Exercise Bouts (HIEB)	0.0	1.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	1.0

Table 5.10 Average (median) percentage of total team performance efforts for individual positions (1 - 5).

Indicator	Loosehead Prop (1) (*n*=30)	IQR	Hooker (2) (*n*=32)	IQR	Tighthead Prop (3) (*n*=31)	IQR	Left Lock (4) (*n*=24)	IQR	Right Lock (5) (*n*=45)	IQR
Ball Carries	4.1	5.3	4.2	2.9	2.8	3.5	4.8	3.4	5.5	3.7
Ball Carries & Try Scored	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Passes	0.7	0.0	1.1	0.0	1.0	1.6	1.2	2.3	1.6	12.8
Kicks	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Tackles Made	8.1	5.2	10.3	4.8	6.7	4.4	10.7	6.2	9.1	6.3
Tackles Missed	0.0	5.3	5.8	15.1	0.0	11.1	4.2	14.3	0.0	9.6
Total Rucks	27.9	13.4	28.3	9.5	25.4	9.3	34.1	11.0	24.2	12.1
Contested Rucks	67.3	21.9	70.0	17.5	52.9	20.5	66.0	14.1	72.2	24.2
Turnover Lost	0.0	0.0	0.0	8.9	0.0	0.0	0.0	6.5	0.0	7.7
Penalty Conceded	0.0	10.3	0.0	0.0	0.0	6.7	0.0	10.9	0.0	0.0
Own Lineout Caught	0.0	0.0	0.0	0.0	0.0	0.0	11.8	22.4	27.8	38.1
Own Lineout Lifter	37.8	40.0	0.0	0.0	25.0	25.7	36.4	35.0	22.2	29.7

Table 5.11 Average (median) percentage of team total performance efforts for individual positions (6 – 10).

Indicator	Blindside Flanker (6) (*n*=30)	IQR	Openside Flanker (7) (*n*=42)	IQR	Number 8 (8) (*n*=12)	IQR	Scrum Half (9) (*n*=36)	IQR	Fly Half (10) (*n*=24)	IQR
Ball Carries	5.0	4.3	5.3	4.6	13.6	11.0	4.2	2.3	4.4	4.1
Ball Carries & Try scored	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Passes	1.2	30.6	1.4	4.0	2.4	8.3	50.9	4.3	17.9	4.1
Kicks	0.0	0.0	0.0	0.0	0.0	0.0	18.9	16.6	56.5	54.5
Tackles Made	12.3	6.1	13.6	5.7	10.3	5.3	4.6	2.7	8.1	4.6
Tackles Missed	4.6	11.1	0.0	12.5	0.0	10.8	7.7	14.3	7.7	14.3
Total Rucks	25.9	13.3	30.9	10.5	24.0	14.1	2.0	1.5	6.5	6.9
Contested Rucks	77.8	19.2	74.5	20.3	78.2	15.7	100.0	0.0	80.0	32.1
Turnover Lost	0.0	8.3	2.5	9.3	7.9	10.6	8.0	13.7	7.1	10.0
Penalty Conceded	0.0	0.0	0.0	7.3	0.0	6.3	0.0	0.0	0.0	0.0
Own Lineout Caught	10.6	20.6	0.0	10.3	0.0	7.4	0.0	0.0	0.0	0.0
Own Lineout Lifter	20.5	34.6	10.0	20.4	8.4	22.1	0.0	0.0	0.0	0.0

Table 5.12 Average (median) percentage of team total performance efforts for individual positions (11 – 15).

Indicator	Left Wing (11) (*n*=40)	IQR	Inside Centre (12) (*n*=37)	IQR	Outside Centre (13) (*n*=65)	IQR	Right Wing (14) (*n*=42)	IQR	Full Back (15) (*n*=34)	IQR
Ball Carries	6.6	4.3	7.2	3.0	7.1	4.7	6.5	5.4	8.4	4.3
Ball Carries & Try scored	0.0	15.2	0.0	0.0	0.0	0.0	0.0	21.3	0.0	0.0
Passes	1.5	10.7	3.3	3.5	2.9	4.7	2.5	2.9	3.7	3.7
Kicks	3.4	5.8	0.0	4.4	0.0	3.0	3.6	5.6	15.5	18.1
Tackles Made	4.9	4.6	9.3	5.9	7.8	4.7	3.7	4.2	3.1	2.3
Tackles Missed	0.0	9.8	7.1	14.3	0.0	11.1	0.0	10.3	0.0	1.0
Total Rucks	8.9	5.7	12.7	7.5	11.7	7.7	7.1	7.0	8.4	8.8
Contested Rucks	75.0	21.0	69.2	22.9	75.0	22.8	81.7	34.1	75.0	17.0
Turnover Lost	8.7	12.5	8.3	13.4	10.0	14.3	8.3	15.3	8.7	13.1
Penalty Conceded	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Own Lineout Caught	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Own Lineout Lifter	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

5.4 Discussion

The findings of the current study demonstrate that during elite English club level rugby union matches, substantial differences in a variety of performance-related measures prevail between the positions broadly classified as forwards and backs, and likewise between six positional sub-groupings and individual player positions. Whilst this knowledge collectively might not be novel from an anecdotal perspective, from an objective and quantifiable point of view, it represents the first of its kind (at the professional club level, and on such a scale) to be reported.

Focusing on the most simplistic classification of player position, analysis revealed that the forwards were involved in markedly more static exertions than the backs (40%, ~ 30 more); an observation reported in previous studies involving elite male and female players. For example, Duthie et al. (2005) reported that male forwards were involved in 33% more static exertions than the backs and Virr, Game, Bekk and Syrotuik (2014) noted a 39% difference between the two groups in women's rugby union. Further, the current findings portrayed a similar trend to that found at international standard by Quarrie et al. (2013), who also reported forwards (~ 55 – 69) to engage in more contact events than backs (~ 13 – 23). Accordingly, when the time spent in static exertions was expressed relative to the total ball in play time, forwards were involved in ~ 13% more than the backs. Of the six positional groups, the second and back rows participated in the most static exertions (between 43 and 45 per match), which was significantly more than the front row. This could, however, be indicative of the amount of time players in certain groups (and in certain individual positions) spent on the pitch since when expressed in relative terms, no substantial differences between the positional groups (or individual positions) existed.

Whilst these frequencies for static exertions by forwards are comparable to the recent findings of Lacome et al. (2014) (around 53 for all forward groups), they are somewhat lower than had previously been reported at the professional club level in rugby. The forward positions have typically been observed to participate (on average) in ~ 59 (Deutsch et al., 2007) and 66.9 (Duthie et al., 2005) static efforts per match during the Super 12s league (southern hemisphere countries including Australia, New Zealand & South Africa), and as many as 89 in previous analysis of the English Premiership (Roberts et al., 2008). However, these differences could be owing to methodological differences, in the definition of a 'static exertion' effort adopted by researchers, or the duration players were on the pitch. For example, Roberts et al. (2008) classified all ruck involvements for 40 minutes of match play and extrapolated the data for 80 minutes of play to estimate the frequency of static exertions which might explain the lower frequency of static exertions in the current study. Furthermore, Roberts et al. (2008) only investigated one team over five matches and hence their data could be indicative of that team's particular playing style. Moreover, similar to findings in soccer (James, Mellalieu & Holley, 2002; Lago & Martin, 2007; Taylor, Mellalieu, James & Shearer, 2008; Tucker, Mellalieu, James & Taylor, 2005), although not measured within this investigation, it is reasonable to suggest that situational factors (such as match location, match status and opposition) could contribute to these differences, particularly when considering the tactical elements of the game.

The higher frequency of static exertions performed by the left locks can be attributed to their greater attendance at rucks (averaging 27 per match) than other positions. This was also reported by Quarrie et al. (2013) whose locks attended the most number of rucks (28.0). Conversely, of the forward positions in the present investigation, the tighthead prop was involved in the fewest number of static exertions (35.0) and except for the hooker position, the least relative amount of time in static exertions (14.1%). Additionally, the same prop position contested the least amount of rucks attended; only ~ 52%, which is substantially less than that of any other front row positions. Nonetheless, except for their higher rate of contested rucks (67.3%), comparable findings were evident for the loosehead prop position. Considering that typically the tighthead and loosehead props also cover the least distances (as revealed in Chapter 4), it could be suggested that the intensity of the physical demands on the musculo-skeletal system from scrummaging (Preatoni, Stokes, England & Trewartha, 2012) is so great it impedes their involvement in other elements of the game. Indeed, it might be that the heavy loads sustained during the scrums subject these particular positions to more transient fatigue (Mohr et al., 2003; Preatoni et al., 2012) that requires a longer duration of reduced activity to aid recovery and impacts on their other KPIs (such as running distances, rucks attended and contested). Obviously, such a statement is speculative given that force-related data (loads) were not measured and other markers of the presence of transient fatigue have not been established in rugby union. Although, alternatively this could be suggestive of different playing styles across teams and individuals; whereas one team may employ a prop player for his ability in open play, another may employ a prop purely for his ability in the scrum, as securing possession is crucial within the game (Quarrie et al., 2013).

It has previously been noted that the back row positions are typically very demanding in nature (Austin et al., 2011a; Duthie et al., 2005; Eaton & George, 2006; Lacome et al., 2014; Quarrie et al., 2013; Roberts et al., 2008). Similar findings are evident in the current study, with the back row players typically involved in the most static exertions, primarily due to their higher frequency counts of tackles and high intensity exercise bouts. Moreover, individual positional analysis revealed that both the blindside and openside flanker positions made the most tackles during match play (12.0 and 12.0, respectively), accounting on average for 12.3% and 13.6% of total team tackles, which is significantly higher than both prop and outside backs positions. These results are consistent with the earlier reported findings of James et al. (2005) who observed the openside flanker, scrum half and blindside flanker completed the most successful tackles (10.6, 10.4 and 9.5, respectively). Similarities were also demonstrated with the international standard game, as Quarrie et al. (2013) noted the flankers and number 8 positions performed the most tackles during matches (14 and 12, respectively). The findings of the present investigation could be expected as it has previously been reported that back row players congregate on the periphery of the ruck with the key responsibilities of both offensive and defensive plays (Deutsch et al., 2007).

Further, the current analysis determined that the back row positions, principally the openside flanker, participated in significantly more HIEB than all the other positions (3.0) with the exception of the blindside flanker (2.0) and the number 8 (3.0). Although these were considerably smaller frequencies than those noted by Austin et al. (2011a) who reported that the forwards participated, on average, in 16 HIEBs per game, such variations could be due to a number of factors. One such factor might be the location of the rugby matches; whether they occur in the northern or southern hemispheres. Whilst a similar standard of play is believed to be represented in elite club level leagues in both hemispheres (Fuller, Raftery, Readhead, Targett & Molloy, 2009), numerous authors allude to disparities across the two hemispheres, particularly in playing styles, albeit in the absence of significant objective evidence. Anecdotally, a faster-paced attacking game in the southern hemisphere has often been referred to, which could be owing to the interpretation of the laws (Roberts et al., 2008), with claims of there being less focus on the scrum breakdown in the southern hemisphere than in the northern. Additionally, the difference in climates, for example drier warmer conditions, could be more suitable to open and attacking play with ball in hand in the southern hemisphere compared to the northern hemisphere where matches are frequently played in less ‘favourable’ conditions (over the autumn and winter months). Arguably, colder, wetter conditions force players to slow the ball down and play more through the forwards and at the breakdown to reduce the likelihood of dropping and knocking on the ball and thus losing possession. Alternatively, methodological disparities in study designs could be an important factor, which could also account for the differences portrayed in the findings of Jones et al. (2015) who determined the frequency of HIEB ranged between 5 ± 4 for the scrum half positions and 13 ± 7 for the loose forwards position. For example, the findings of Austin et al. (2011a) were based on only 20 players from seven matches (and thereby less representative), compared to the current 149 players and a total of 524 data sets spanning three seasons of competition. In addition, Austin et al. (2011a) identified sprint efforts subjectively via video footage, which is likely to be a less precise method than the current investigation's use of GPS units and individual speed zones to objectively identify maximal individual sprint efforts. Although, Jones et al. (2015) also utilised GPS devices to help determine HIEB methodology, disparities were evident in the use of a predetermined sprint speed classification zone and the inclusion of acceleration-related data, which could account for the greater HIEB during match play.

Nonetheless, albeit the frequency of HIEB involvement of the back row positions were smaller in the current investigation than previously reported, when this is coupled with the higher number of tackles they typically make during match play, it is likely that the physiological load imposed on such players is high (Gabbett, 2013b; Johnston & Gabbett, 2011). Additionally, the frequency of tackles has previously been shown to correlate proportionally with muscle damage (Cunniffe, Hore, Whitcombe, Jones, Baker & Davies, 2010; Takarada, 2003) thus the demanding requirements of the back row positional groups are clear. Indeed for all forward positions, their high involvement in static exertions illustrates the demanding nature of their roles within matches as maximal isometric contractions require a high work load and elicit high heart rates and overall cardiovascular stress (Patterson, Pearson & Fisher, 1985; Virr et al., 2014). Whilst the frequency of HIEB is relatively low in the present study, often such efforts take place during crucial aspects of match play (Spencer et al., 2004) and players need to be able of cope with the demands irrespective of when they occur.

Whilst as a group the back positions are renowned for their locomotive involvement, primarily their sprinting ability rather than their participation in static exertions, tackles, rucks, repeated high intensity efforts and set pieces (Austin et al., 2011a; Austin et al., 2011b; Deutsch et al., 2007; Duthie et al., 2005; Duthie et al., 2006; Eaton & George, 2006; Lacome et al., 2014: Quarrie et al., 2013; Roberts et al., 2008), the present findings illustrated their varying involvement in static exertions, particularly in that the inside and outside centres were involved in the greatest frequency of static exertions (15.0 and 14.0, respectively), primarily due to their superior involvement in tackles. That the current data shows the inside centres and the fly half positions typically made the greatest number of tackles during matches - significantly more than the scrum half and all outside backs positions - is in contrast to the findings of Quarrie et al. (2013) who reported the scrum half to have one of the highest tackles counts. To the author's knowledge this is the first study to show that the fly half position is involved in a similar number of tackles to the forwards. This could be indicative of the differences in international and professional club level rugby union and different playing styles adopted, or alternatively, the opposition's tactics employed (Gabbett, 2013b). For example, at the club level, an opposing team might have identified a defensive weakness in the fly half position of a particular team and thus proceeded to attack that position as part of their game strategy, yielding a greater frequency of tackles by the fly half. Moreover, the fly half position is traditionally renowned for its decision making ability in identifying and outlining the playing strategy of the team. It could be that the fly half positions aim to kick-chase the ball into the opposition's half to gain territory (and limit the opposition's territory advancement) and as a consequence it is often the first line of defence which has to make the most tackles. Interestingly, the present investigation illustrated that similarities were evident in the frequencies and percentages of total team tackles between the fly half positions (9.0 and 8.1% respectively) and the second and front row positions, which has scarcely been shown previously. Likewise the inside centre (9.0 and 9.3%) position also illustrated similarities with the second and front row positions, opposing previous reports where most comparable match demands of the inside backs have been with the back row positions (Austin et al., 2011b; Deutsch et al., 2007). Again, such variability could be because of the different methods employed across investigations, such as the calculation of the time spent on the pitch by each player (the associated cut-off time stipulated), and the pre-planned tactical strategies of one team against another.

In keeping with the findings of James et al. (2005) and Quarrie et al. (2013), the outside back positions were characterised by performing the least number of tackles and static exertions, as was the scrum half position. Considering the role of the scrum half is to follow the pattern of play, and act as a link between the forwards and the backs in distributing the ball (Bompa & Claro, 2009; Deutsch et al., 2007; Eaton & George, 2006), such a finding would be expected. Indeed, this is reinforced by the scrum half being seen to be involved in more than 50% of all team passes. The outside back positions had the highest frequency of ball carries, with the full back the most (on average 8 times) per match. Yet, in contrast to recent findings (on international players) that centres and wings scored more tries than the other positions (Quarrie et al., 2013), the only significant difference exposed in the number of tries scored across the positions was between the right wing and loosehead prop. This lack of statistical difference, however, might in part be owing to the use of the stringent Bonferroni technique for maintaining the risk of committing a type I error to an acceptable level. For example, if no correction had been applied both wing positions would have scored significantly more tries than the all individual positions with the exception of the number 8 and the outside centres.

An important and interesting finding of the current study was that although the full back had the most ball carries and percentage of team ball carries amongst the back positions, it was typically the number 8 position that carried the ball most overall, which has not be identified previously (James et al., 2005; Quarrie et al., 2013). Such a fact could potentially illustrate a change in the role of the number 8 positions in the contemporary game compared to earlier findings which have typically analysed games from the early 2000s (James et al., 2005). Arguably, this might reflect that the number 8 position plays in a way that is similar to the outside back positions, particularly whilst in attack, frequently making themselves available to collect the ball and run towards the opposition. It could, however, be owing to the number of scrums participated in during the match and consequently a reflection of the number of ball carries from the base of the scrum towards the opposition defensive line.

5.5 Practical Applications

The findings of this chapter provide practitioners with a contemporary understanding of the performance-related demands of elite rugby union within the English Premiership. This information could be utilised for a number of purposes; to assist in designing position-specific training programmes; to help inform recovery schedules and to aid in forming position-specific return to play protocols for teams competing in the English Premiership. Additionally, this chapter provides essential information for practitioners when constructing conditioning programmes, as it enables training sessions to be created that can replicate demands, overload or reduce match stimuli to ensure players are optimally trained for competition. Whilst tactical and technical team training sessions should be inclusive of all variables, the findings indicate that specific individual positions could benefit from greater emphasis in training on particular indicators. For example, although all positions were involved in a number of static exertions during match play, the forwards positions were found to participate in significantly more (typically ~ 30 more efforts) than the backs positions and thus should be reflected in conditioning programmes. More specifically individual positional analysis revealed that the loosehead and tighthead prop positions were involved in the least number of rucks and tackles, which was speculated to be due to the demands of scrum activity. Therefore it would seem beneficial for the prop positions to focus some aspects of training to scrummaging, in both developing the physical attributes (strength and power) required to cope with the demands during competition and in developing optimal technique.

The lock positions were found to attend the greatest number of rucks (~43) per match. Particular attention should be paid to developing strength and endurance fitness in such positions to aid in the sustainability of high ruck frequency attendance. Moreover considering the number of infringements that occur at the breakdown, time should be dedicated to the technical aspect of rucking, both in a "fresh" and fatigued state to try and help reduce conceding penalties in these positions during the game. Similarly the back row positions were involved in a large frequency of ruck although particularly the flanker positions demonstrated increased involvement in tackles (characteristically 12 per match) and therefore training programmes should reflect this. Such positions could benefit from additional isometric static exercise training to aid in eliciting the physical adaptations required to meet the demands over an 80 minute period. Moreover, again tackling technique should be practiced both in a "fresh" and fatigued state where possible. This is similar for the inside backs positions as the findings highlighted, the inside centre and fly half positions are typically involved in the greatest number of tackles (of the back positions) during matches (~ 9 per game). Whereas for the outside backs positions whilst previously noted the development of speed is imperative for these positions (Chapter 4) the current findings suggest particular attention should be given to developing speed whilst carrying the ball as their involvement in ball carries is greatest across all the back positions.

Moreover, the findings could be utilised in determining the length of recovery periods post match. As a group, the forwards positions are characteristically involved in a greater number of static exertions and thus sustain greater loads during match play. Considering the high correlation between the frequency of tackles and recovery time (Cunniffe et al., 2010; Takarada, 2003) this information could help practitioners in determining recovery periods per position or positional group following match play and even training sessions. For example, as the forwards are involved in ~ 30 more static exertions than the backs positions and on average make more tackles, it is feasible to suggest longer recovery periods post matches could be favourable. Furthermore, considering the re-occurrence of injuries in the English Premiership has previously been reported as high as 19% (Brooks et al., 2008) this objective data, combined with the findings of chapter 4, could aid practitioners in developing position specific return to play protocols that are more reflective of match demands, potentially reducing the re-occurrence of injuries. For example, if an openside flanker is returning to play, using the current findings strength and conditioners could design a session to test their ability to sustain the average match demands. Therefore on average they would have to be able to endure ~ 46 static exertion including, 23 rucks of which 75% were contested, 12 tackles, 3 HIEB, 13 scrums, 1 passes and 1 lineout lift, in addition to covering on average 5.7 km (64 $m \cdot min^{-1}$) and reaching speeds of typically 28.4 $km \cdot h^{-1}$. If they were capable of doing so practitioners could have increased confidence the player could be successfully returned to competitive play.

5.6 Summary

On reflection, the current analysis has, in the main, provided values for the typical performance-related demands of rugby union played at the elite level in England between 2010 and 2013. In accessing one of the largest data sets across professional rugby union, distinctive positional variability in various indicators of performance has been shown to exist in the English Premiership competition. In general, the analysis concurred with previous findings that the forward positions are responsible for more static efforts overall and relative to ball in play time than the backs. It demonstrated that back row players, in particular those in the blindside and openside flanker positions, fill one of the most demanding positions across the team, being involved in the most number of team tackles and high intensity repeated efforts. In addition, the analysis provided some new insight in that whilst the outside back positions, particularly the full back position, are typically characterised as the dominant ball carriers and play-makers in the team, it is the number 8 position that has the most ball carries and percentage of team carries, and reflects a hybrid position in terms of performance demands.

It should be noted whilst a large data set such as this implies that the findings provide a better representation of the league upon which it is based, Hughes and Bartlett (2002) cautioned that in such cases small, but meaningful differences may be lost or overlooked amidst the 'typical' values. Nonetheless, the findings of the current investigation have provided valuable knowledge of the average position-related demands of participating at the professional club level. This data highlights the varying requirements of the individual positions, which could be used by practitioners to prepare players optimally, aid in devising appropriate recovery protocols and guide medical staff in developing individual specific return-to-play protocols (Reid et al., 2013).

However, whilst the average demands of the game provides a good insight into what is required to compete at the professional level, considering there are numerous stoppages in rugby union when the ball is out of play, the findings from full match analysis could potentially underestimate, or fail to identify, the more demanding aspects (most intense scenarios) during competition which could influence match outcomes. Additionally, previous findings from different codes of team sports (soccer, rugby league, Australian rules football league) have suggested positional demands may alter throughout match play owing to factors such as fatigue, pacing elements, competition strategy, time of the season, score status, opposition or even weather and hence movement and performance aspects may fluctuate accordingly. However, to date few researchers have attempted to identify the changes in movement patterns throughout the duration of elite rugby union matches. Such information could indeed be indispensable to practitioners and therefore it is plausible that further examination of the game is warranted to provide a more comprehensive analysis of elite English rugby union.

Chapter 6: Match Fluctuations in Running Performance and Static Exertions in Elite Rugby Union

6.1 Introduction

TMA and GPS have provided a general understanding of the physical demands of elite rugby union, particularly when assessing average movement patterns of players participating in full matches (Austin et al., 2011b; Duthie et al., 2005; Lacome et al., 2014; Quarrie et al., 2013; Roberts et al., 2008). The activity profiles of elite rugby union players established in Chapter 4 have demonstrated that backs cover greater distances than the forwards (by ~ 900 m), with total distance covered during the match approximately 5,222 m for forwards and 6,134 m for backs. Furthermore, clear differences *within* positional groups were apparent, with scrum halves covering the greatest distances (6,542 m), and the tighthead props covering the least (4,316 m). However, full match analysis potentially underestimates intense periods of play and the associated physiological stress accompanying such periods (Bradley & Noakes, 2013; Waldron, et al., 2013). To-date, few studies have considered positional movement changes over the course of elite rugby union match play, and the extent to which, if at all, performance alters or players show signs of fatigue during competition.

Fatigue can be defined as "decrements in muscle function and performance" (Abbiss & Laursen, 2005, p. 287). In clinical and research settings, a maximal voluntary contraction is deemed the "gold standard" indicator of fatigue. However, such measurements are not easily obtained during team sports in an applied setting, and thus are scarcely used (Duffield, Murphy, Snape, Minetti & Skein, 2012; Rampinini et al. 2011). As such, alternative methods are often used to determine fatigue and match performance in team sports. One such widely accepted and non-invasive method is the measurement of a change in high intensity running (HIR) (e.g. Bangsbo et al., 1991; Bradley & Noakes, 2013; Carling & Dupont, 2011; Mohr et al., 2003; Rampinini et al., 2007b, Rampinini et al., 2009; Waldron et al., 2013). Whilst HIR can vary by ~15% (Kempton, Sirotic & Coutts, 2014) in association with situational variables such as match outcome (Black & Gabbett, 2014; Gabbett et al., 2013; Lago, Casais, Dominguez & Sampaio, 2010), match location (Lago et al., 2010), ball-in-play time (Carling & Dupont, 2011), phase of play (Gabbett, Polley, Dwyer, Kearney & Corvo, 2014), location on the pitch (Gabbett et al., 2014), playing standard and physical fitness (Johnston, Gabbett & Jenkins, 2014b), it also shares a strong association with physiological disturbances associated with fatigue, such as muscle glycogen depletion (Krustrup et al., 2006). Furthermore, in soccer and rugby league, superior teams (i.e. elite) characteristically perform greater HIR distances than sub-elite teams (Bangsbo et al., 1991; Gabbett, 2013; Mohr et al., 2003; Sirotic et al., 2009), and greater HIR in a game is well correlated with measures of superior physical fitness such as aerobic and intermittent running capacity (Johnston et al., 2014b; Krustrup, Mohr, Ellingsgaard & Bangsbo, 2005).

As discussed in previous chapters, rugby union is a multifaceted game requiring locomotive movements and (potentially maximal) isometric muscle contractions in the form of static exertions (including scrummaging, tackling, rucking and mauling). As static exertions increase the cardiovascular stress placed on players (Patterson, Pearson & Fisher, 1985) and the frequency of collisions correlate highly with muscle tissue damage (Takarada, 2003), it would seem prudent that the inclusion of such efforts should be monitored as an indicator of fatigue and performance in rugby union.

Fatigue in team sports has been studied most extensively in soccer, where it is commonly accepted that performance, and in particularly HIR, declines in the second half of matches and more notably towards the end of a match (i.e. the final 15 minutes) by approximately 14 - 45% in HIR and 43% whilst sprinting (Mohr et al., 2003). Similar decrements in HIR (ranging between 11.5% and 30.5%) have been observed in rugby league (Sirotic et al., 2009; Sykes et al., 2011) and Australian rules football (Aughey et al., 2010; Coutts et al., 2010).

However, in rugby union the manifestation of fatigue as a decline in performance has seldom been presented (Duthie et al., 2005; Lacome et al., 2014; Roberts et al., 2008). The limited research so far has assessed small sample sizes, failed to compare changes between positional groups, or only compared intensity between halves rather than at smaller time intervals.

Duthie et al. (2005) initially reported no differences in HIR, various movement parameters or the number of static exertions between halves in rugby union matches. In agreement, Cunniffe et al. (2009) observed little change in high-intensity running, sprinting, distance covered, average speed and number of accelerations in elite rugby union players, although these observations were limited to two individuals over the course of one match. In a more comprehensive analysis, Roberts et al. (2008) examined changes in movement intensity and static exertions during a match in the English Premiership. They reported that there was no difference in distance covered in HIR or sprinting from the first to the second half of the match. However, when the match was segmented into 10 minute time periods, there was a significant reduction in distance covered in the 50 - 60th minutes and 70 - 80th minutes compared to the first 10 minutes. Non-significant reductions in HIR were reported over the 10-minute periods (~ 35 m), which may have been due to inadequate statistical power associated with the relatively small sample size (n = 10). Accordingly, in a recent investigation into temporal changes in movement during rugby union utilising a larger sample (n=71), players demonstrated a reduction in HIR in the 30-40th and 60-70th minutes of a game (Jones et al., 2015). The same study also identified few significant changes in the number of contacts players were involved in across 10-minute periods. However, the analysis in this study was confined to one team only, and the authors did not consider differences between positional groups.

In addition to changes in HIR, to-date no studies have considered the phenomenon of 'transient fatigue' during a rugby union match. This phenomenon has been observed in other team sports, and is characterised by a 'peak' 5-minute period of HIR, followed by a 5-minute period of HIR below an individual's match average by as much as 50% (Bradley, Di Mascio, Peart, Wooster, Olsen & Sheldon, 2010; Bradley & Noakes, 2013; Carling & Dupont, 2011; Mohr et al., 2003; Rampinini et al., 2007b). It is also noteworthy that changes in HIR in team sports, both over the course of a match, and on a transient basis, have previously been ascribed to different pacing strategies adopted by players. In this context, pacing is thought to occur in an attempt to maximise physiological work whilst preventing a 'catastrophic' disturbance to physiological homeostasis associated with fatigue (Edwards & Noakes, 2009; St. Clair Gibson, Lambert, Rauch, Tucker, Baden, Foster & Noakes, 2006). Thus, it has been proposed that players modify their exertions at a macro- (whole match pacing strategy), meso- (altering exertions between halves) and micro- (altering exertions on a continual basis, as with 'transient' fatigue for example) level to manage effectively their physiological resources (e.g. muscle glycogen) over the course of a game (Edwards & Noakes, 2009; Tucker & Noakes, 2009). In rugby union, this management of resources is likely to be dependent on a player's understanding of the expected duration and intensity of the exercise bout (Sampson, Fullagar & Gabbett, 2015; Waldron et al., 2013), and external factors such as score line and climate (Aughey, Goodman & McKenna, 2014; Waldron & Highton, 2014).

Whilst different pacing strategies have been described in soccer (Bradley & Noakes, 2013; Carling & Bloomfield, 2010), Australian rules football (Aughey et al., 2010) and rugby league (Black & Gabbett, 2014; Waldron et al., 2013), few studies have considered the potential pacing strategies that elite rugby union players adopt during a match. Therefore, the purpose of this study was to identify changes (every 5-minutes) in HIR and static exertions across elite rugby union match play in different positional groups, and thus determine the extent of reductions in HIR potentially associated with fatigue, the extent of 'transient' fatigue, and finally, the potential pacing strategies adopted by rugby union players.

6.2 Methods

6.2.1 Participants

Following approval from the Faculty of Applied Sciences Research Ethics Committee and consent from eight professional clubs from the English Premiership, a total of 207 elite rugby union players (age 27.5 ± 4.2 y; body mass 103.8 ± 12.6 kg; stature 1.87 ± 0.07 m), participated in the study.

6.2.2 Procedures

Each of the eight participating clubs nominated a strength and conditioning coach or a sports scientist to be responsible for providing and fitting each participant with a GPS unit on a match day. Each consenting player wore a GPS unit (mass = 86 g; size = 0.8 x 0.4 x 0.2 cm) (SPI Pro, GPSports, Canberra, Australia) in a padded protected harness, positioned in the area of the upper thoracic spine, between the left and right scapulae. The GPS device captured data at a sampling frequency of 5 Hz and had an inbuilt tri-axial accelerometer sampling at a rate of 100 Hz. All participants were familiarised with the devices during training sessions prior to wearing them in matches.

The GPS units were switched on at least 10 minutes prior to the game to ensure a full satellite signal was received. At the end of each match the GPS data files were downloaded onto a personal computer and analysed with Team AMS software (version 10; GPSports, Canberra, Australia). A note of the Greenwich Mean Time at the beginning and end of the match was made and later synchronised with the GPS raw data. The raw data files were later segmented into five minute playing periods, then exported into Microsoft Excel (Microsoft Corporation, USA), and subsequently SPSS (version 21) for statistical analyses.

All matches were recorded with a video camera at a frame rate of 25 Hz, which was elevated from the pitch level and positioned on (or as near as possible to) the half way line. For each match in which players had worn GPS devices (and thereby provided locomotive data, as reported in Chapter 4), the corresponding video footage was provided for performance analysis by PGIR (an analysis franchise for the England Rugby Football Union). The codes were synchronised with the video footage and the raw GPS data which were subsequently edited and adapted as required for 5 minute analysis by an analyst through the use of SportsCode software (Sportstec, Lower Hutt, New Zealand) and Team AMS.

6.2.3 Player groupings

For data analysis players were assigned to one of six positional groups (adapted from Deutsch et al., 2007; Duthie et al., 2005; Roberts et al., 2008), with the scrum halves assigned a category of their own due to their unique role within the game (Deutsch et al., 2007; Duthie et al., 2005; Lacome et al., 2014; Roberts et al., 2008). These groups were as described in Chapter 4 (4.2.3, pp.136). For the analyses of movement changes throughout a match only players who had completed the full match were analysed (n = 330, GPS files, 121 rugby union players). Whole match analysis consisted of the following: front row (n = 34); second row (n = 46); back row (n = 57); scrum half (n = 16); inside backs (n = 85) and outside backs (n = 92). However, all the performances of players starting the match (regardless of playing duration) were included in the analysis of the most intense periods of play (peak 5-minute periods), resulting in the analysis of 624 performances. This comprised: front row (n = 136); second row (n = 84); back row (n = 97); scrum half (n = 44); inside backs (n = 123) and outside backs (n = 140).

6.2.4 Match-related performance variables

Players' movements were analysed as total distances, distances covered in low intensity running (LIR) and high intensity running (HIR) relative to time ($m \cdot min^{-1}$). HIR was identified as a movement above 51% of individual maximum running speed and LIR below 51% of individualised maximum running speed (attained during match play over the three years) in accordance with previous literature (Venter et al., 2011).

Frequencies of static exertions were determined through video analysis and identified as the total number of static exertions including scrums, contested rucks, mauls, and tackles (Roberts et al., 2008). A scrum was formed when "eight players from each team, bound together in three rows for each team, close up with their opponents so that the heads of the front rows were interlocked" (IRB Laws, 2003). A player was identified as being engaged in a scrum once the shoulders of the front row forwards were touching and ended once the ball had either left the scrum or the referee stopped play (Austin et al., 2011b). A ruck was identified as "a phase of performance where one or more players from each team, were on their feet, in physical contact, close around the ball on the ground and open play had ended. A player was involved in a ruck when they attended a ruck and used their feet to try to win or keep possession of the ball, without being guilty of foul pay" (IRB Laws, 2003). A contested ruck was subjectively identified when a player performed visible static exertions and contested for the ball whilst in the ruck. A tackle was identified to have occurred "when the ball carrier was held by one or more opponents and was brought to ground" (IRB Laws, 2003).

To examine the relationship between movement and performance changes ($m \cdot min^{-1}$, HIR $m \cdot min^{-1}$ and static exertions) over the duration of match play, analysis was carried out across the first and second half (40 minutes match play, plus stoppage time) and by comparing the first 5-minute period (0-5 minutes) with the eight subsequent 5-minute periods in each half (5-10, 10-15, 15-20, 20-25, 25-30, 30-35, 35-40, 40+) (to avoid overlap 5 minute segments were calculated, for example, as 5 min 1 sec to 10 min, 10 min 1 sec to 15 min). To account for stoppage time (40+ minutes) the frequency of static exertions were normalised to 5-minute for that period. The most intense period of match play was separately identified as peak relative distance in high intensity running ($m \cdot min^{-1}$) and the peak frequency of static exertions during any 5-minute period throughout the match (in the manner of Bradley, Sheldon, Wooster, Olsen, Boanas & Krustrup, 2009; Bradley & Noakes, 2013; Carling et al., 2008; Mohr et al., 2003). For comparative purposes, the 5-minute period subsequent to this peak, and the average 5-minute period were also identified (for both HIR and static exertions).

6.2.5 Statistical Analyses

Analyses were performed using the statistical software SPSS Inc. (version 21). Assumptions of normality and homogeneity of variance were satisfied according to the Shapiro-Wilk and Levene's test, respectively. A three-way analysis of variance (ANOVA) was employed to examine the interactions between halves [2], 5-minute periods [9] and positional groups [6] for each dependent variable. Additionally, a two-way analysis of variance (ANOVA) was used to examine the interaction between time periods [3; peak period, subsequent period and average periods] and positional groups [6] for HIR and static exertions. Where significant interactions were evident ($P < 0.05$) post-hoc analyses, consisting of paired sample *t*-tests for changes between halves and 5-minute periods, and independent *t*-tests for positional differences, were applied to determine where the differences lay. Bonferroni adjustments to the alpha were applied to off-set the increased risk of a type I error that occurs when conducting multiple comparisons.

6.3 Results

6.3.1 Distance covered

ANOVA revealed a significant main effect of halves (F = 59.9, $P < 0.0005$) with the overall 1st half mean (67.4 $m \cdot min^{-1}$) being larger than the 2nd half (63.1 $m \cdot min^{-1}$), and significant effects for both the 5-minute periods (F = 48.8, $P < 0.0005$) and the positional groups (F = 22.7, $P < 0.0005$). Post-hoc analyses highlighted significant ($P < 0.003$) differences between all positional groups (front row = 58.6, second row = 58.8, back row = 64.4, scrum half = 74.9, inside backs = 69.7 and outside backs = 65.1 $m \cdot min^{-1}$) with the exception of the front and second row, back row and outside backs, and scrum half and inside backs. The three-way interaction of the three factors was not significant (F = 0.9, $P < 0.57$), but the two-way interactions of 5-minute periods x positional groups (F = 1.4, $P < 0.04$) and half x 5-minute periods (F = 5.0, $P < 0.0005$) were. Post-hoc analyses of these revealed that players (overall) covered significantly ($P < 0.0005$) more distance ($m \cdot min^{-1}$) in the initial 5-minutes of match play then all the subsequent 5-minute periods within the first half, and similarly in the second half, with the largest declines evident in the latter aspect of each half (Figure 6.1). A general trend was evident across all positional groups displaying a decrease following the initial 5-minutes of the first and second half of the match, although the precise time of this decline appeared dependent on position (Figure 6.2). Total distances ($m \cdot min^{-1}$) in the first four 5-minute (0-20 minutes) segments of the second half were significantly less ($P < 0.05$) when compared to the same period in the first half (Figure 6.1), with the largest reductions in the initial 0-5 minutes apparent for the second row, back row, inside backs and outside backs displaying declines of 12.3%, 16.0%, 8.4% and 9.1%, respectively, albeit not significant (Figure 6.2).

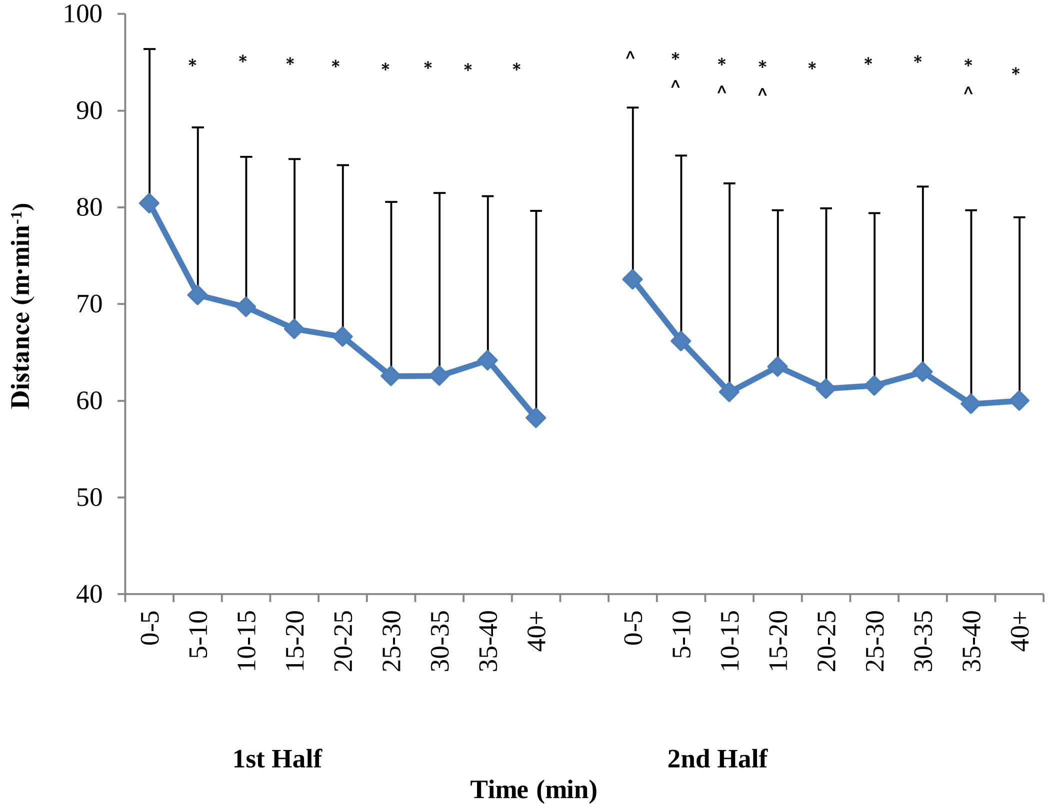


Figure 6.1 Total distances (m·min^{-1}) each half across 5-minute intervals for all positions.

*Significant differences from initial 5-minute periods in each half. ^Significant differences between halves

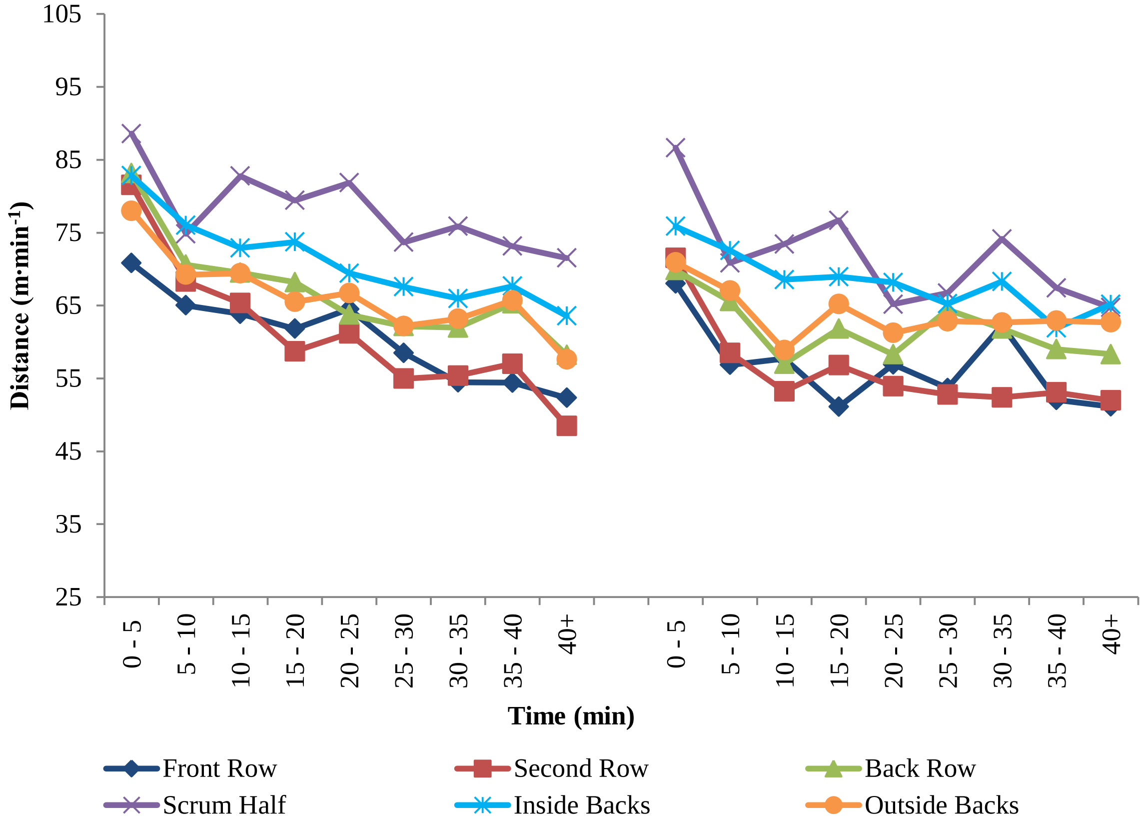


Figure 6.2 Total distances (m·min^{-1}) across 5-minute intervals per positional group.

6.3.2 HIR

A significant main effect of halves (F = 45.0, P < 0.0005) was observed, with the overall 1st half mean (10.8 m·min^{-1}) being higher than the 2nd half (9.1 m·min^{-1}). Likewise for the 5-minute periods (F = 41.0, P < 0.0005) and positional group (F = 5.9, P < 0.0005) factors. In particular, post-hoc analysis of the positional group effect (means: front row = 9.7, second row = 9.2, back row = 11.1, scrum half = 10.3, inside backs = 11.0 and outside backs = 8.4 m·min^{-1}) revealed the back row to be as high as the inside backs, and both positions to be significantly higher than the outside backs. Whilst the three-way interaction was not significant (F = 1.0, P < 0.486), significant two-way interactions were observed for 5-minute periods x positional groups (F = 2.6, P < 0.0005) and 5-minute periods x half (F = 2.9, P < 0.003). Post-hoc analyses revealed that HIR significantly reduced from the initial 5-minute periods in both the first and second half to the subsequent 5-minute periods (Figure 6.3) in particularly in the last 5-, 10-minutes of play. Further significant differences were observed in the 5-minute periods between halves, highlighting a reduction in HIR in the second half, particularly in the first 25 minutes compared to the first half (Figure 6.3). Although not significant, there were sporadic declines in HIR within halves (Figure 6.4) compared to the initial 5-minutes per positional group. The largest reductions in the latter aspect of the match occurred in the front row (~ 45%), second row (~ 62%) and scrum half (~ 47%) positions and the least in the back row (~ 37%) inside backs (~ 23%) and outside backs (~ 29%).

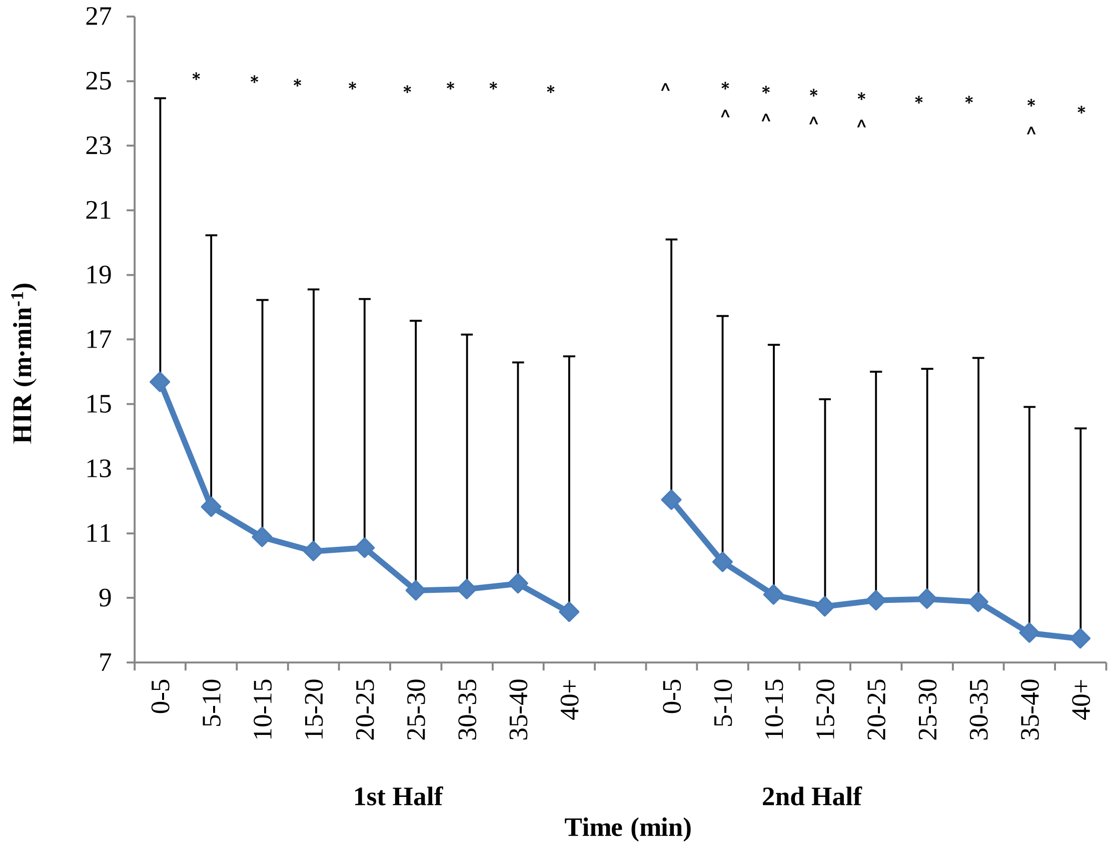


Figure 6.3 HIR (m·min^{-1}) across 5-minute intervals for all positions. * Significant differences from initial 5-minute periods in each half. ^Significant differences between halves.

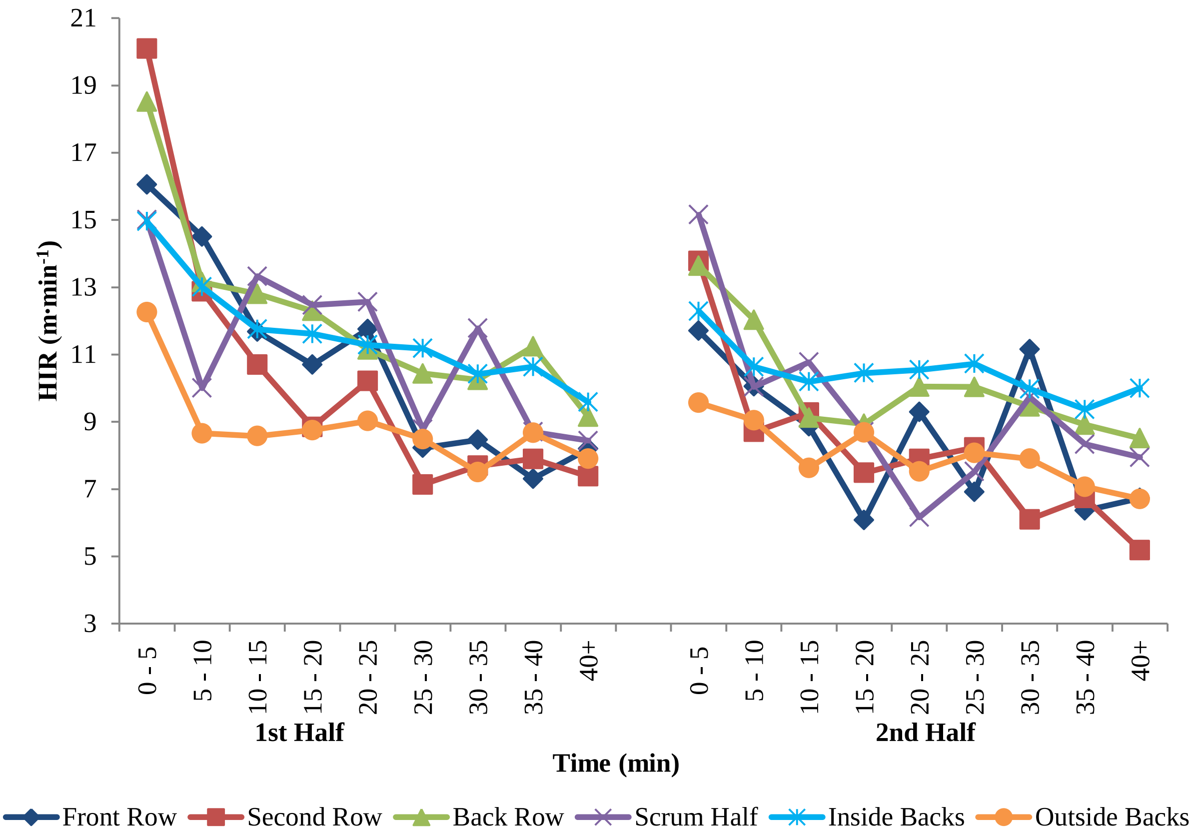


Figure 6.4 HIR (m·min^{-1}) across 5-minute intervals per positional group.

6.3.3 LIR

A significant main effect of halves was evident (F = 38.3, P < 0.0005) with the overall 1st half mean (56.6 m·min^{-1}) greater than the 2nd half mean (53.9 m·min^{-1}). This was similar for the 5-minute periods (F = 29.4, P < 0.0005) and positional group factors (F = 28.0, P < 0.0005). Post hoc analysis of positional group effect (means: front row = 48.9, second row = 49.4, back row = 53.3, scrum half = 64.5, inside backs = 58.8 and outside backs = 56.7 m·min^{-1}) revealed significant differences were evident between all positional groups with the exception of the front and second row and the inside backs with the outside backs. The three-way interaction was not significant (F = 1.1, P < 0.35), and of the three two-way interactions only the halves x 5-minute periods was (F = 4.9, P < 0.0005). Post-hoc analysis illustrated that players (overall) covered significantly greater distances (P < 0.003) in the initial 5-minute periods in LIR, in both the first and second half, in comparison to subsequent 5-minute periods (Figure 6.5), with greatest decline evident at the latter stages of each half (Figure 6.5). Between half differences were also present between the corresponding periods in the first and second halves, particularly between the 1st 0-5 minute, 10-15 minute, 20-25 minute and 35-40 minute periods (Figure 6.5). Figure 6.6 displays the trend across the 6 positional groups with the scrum half position covering the greatest distance in LIR across match play and in the initial 5-minutes of the first and second half.

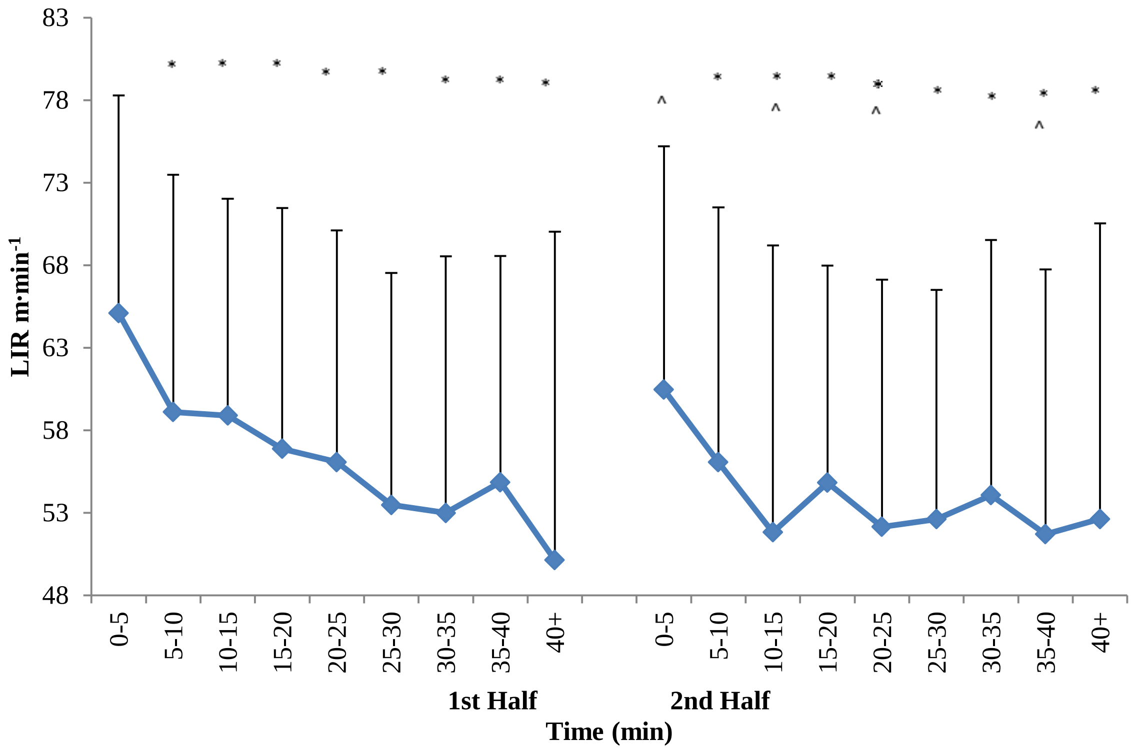


Figure 6.5 LIR (m·min^{-1}) across 5-minute intervals for all positions. * Significant differences from initial 5-minute periods in each half. ^Significant differences between halves.

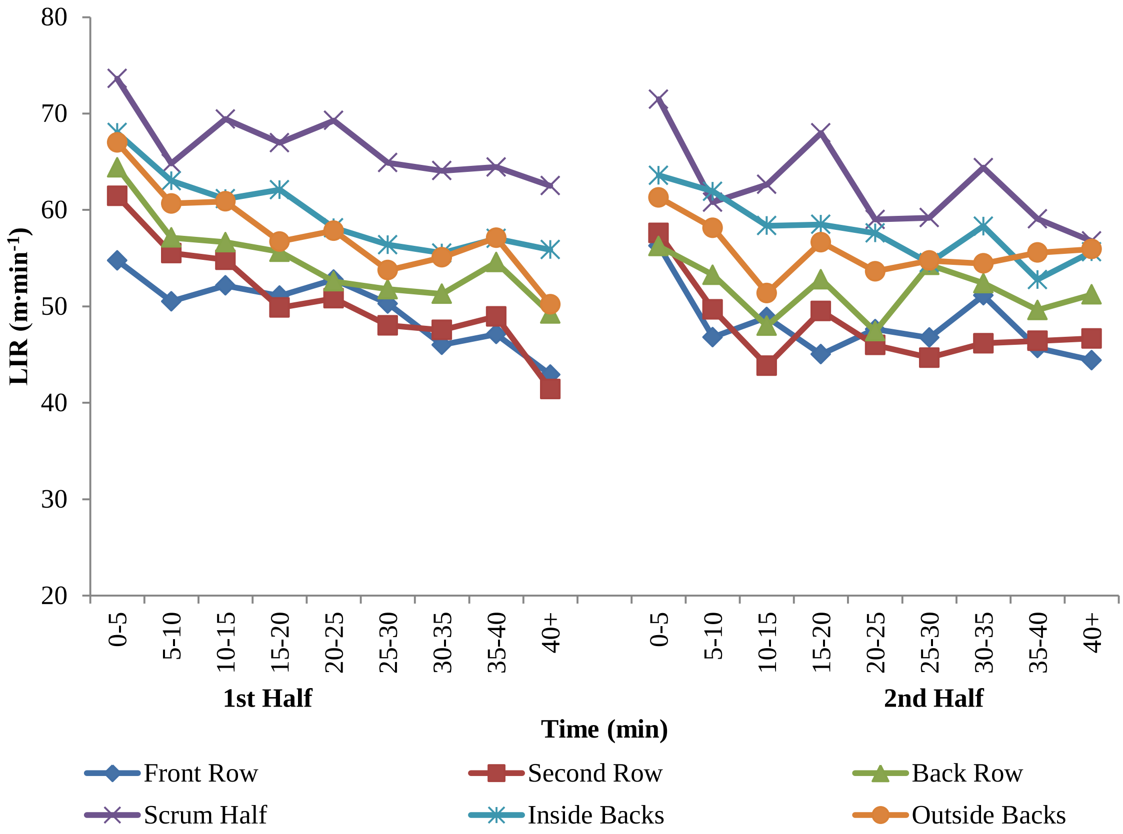


Figure 6.6 LIR (m·min^{-1}) across 5-minute intervals per positional group.

6.3.4 Static exertions

The main effects of the 5-minute periods (F = 3.4, *P* < 0.001) and positional groups (F = 437.7, *P* < 0.0005) were significant, but not so for halves (F = 0.2, *P* < 0.674). Post-hoc analysis revealed significant (*P* < 0.003) differences between all the means of all the positional groups with the exception of the second row (2.5 contacts per 5-minute period) and front (2.3 contacts per 5-minute period) and back row (2.6 contacts per 5-minute period) and between the scrum half (0.4 contacts per 5-minute period) and the outside backs (0.6 contacts per 5-minute period). Whilst the three-way interaction was not significant (F = 1.1, *P* < 0.279), of the three two-way interactions only that of halves x 5-minutes periods was (F = 2.6, *P* < 0.009) (Figure 6.7). Post-hoc analysis of this revealed that the frequency of static exertions was only significantly (*P* < 0.003) reduced at 30-35 minutes and 40+ minutes when compared to the initial 5-minute period in the first half. However, substantial (*P* < 0.003) reductions in the 5-minute periods after the initial 5-minutes of the second half were evident (with the exception of the 5-10 and 30-35-minute periods). Whilst not significant, Figure 6.8 appears to show that static exertions were greatest in the initial 5 minutes of the second half compared to the first, particularly for the front, second and back row position (2.91 – 3.22 static exertions).

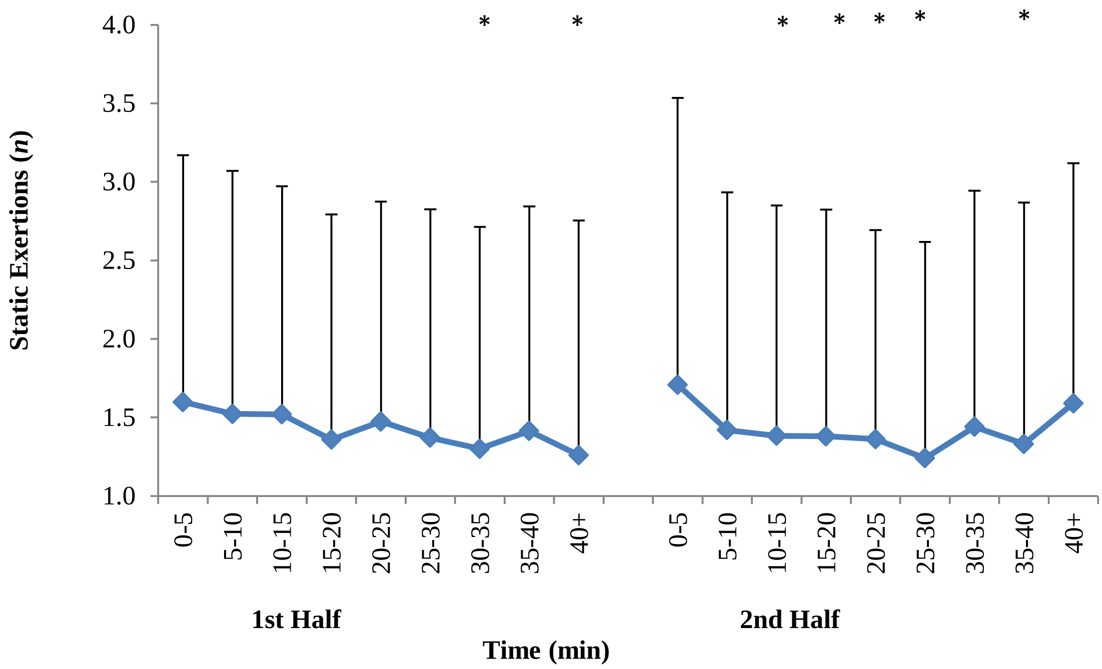


Figure 6.7 Static exertions across 5-minute intervals for all positions. *Significant differences from the initial 0-5 minutes across all positional groups.

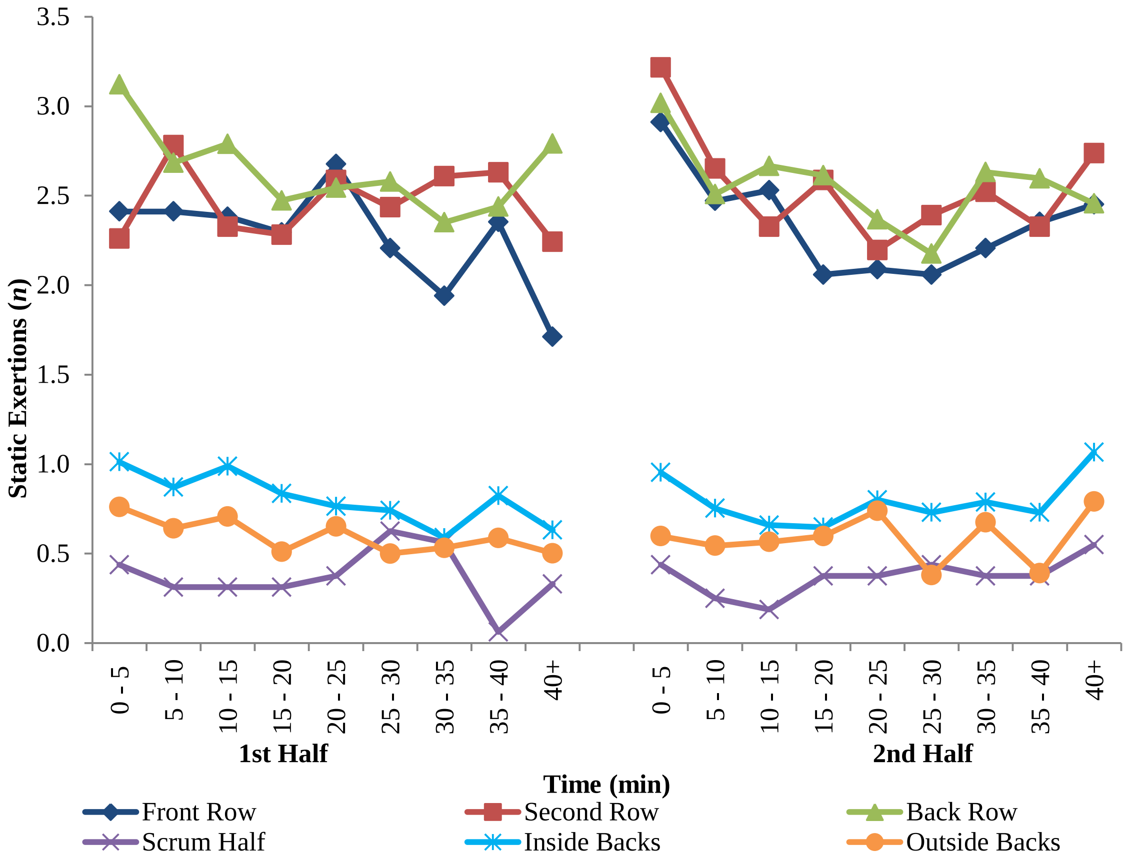
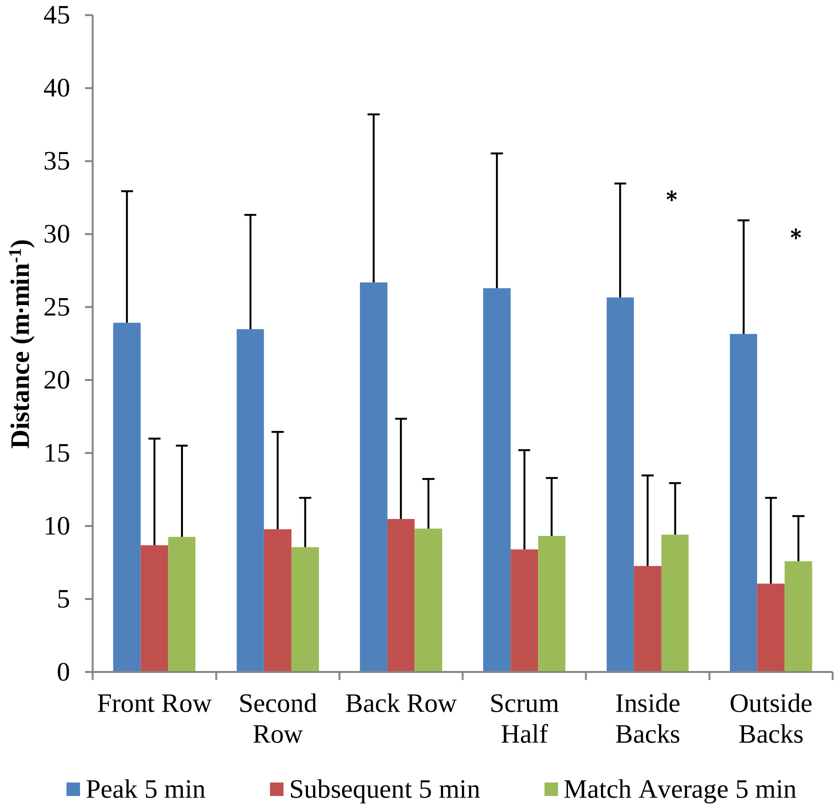


Figure 6.8 Static exertions across 5-minute intervals per positional group.

6.3.5 Peak periods of HIR and static exertions

ANOVA revealed a significant main effect of time periods (F = 1,658.6, $P < 0.0005$) and positional groups (F = 6.2, $P < 0.0005$) on HIR. Post-hoc analyses demonstrated peak HIR (mean = 25.0 m·min^{-1}) was significantly ($P < 0.0005$) greater than the subsequent (mean = 8.4 m·min^{-1}) and average (mean = 9.0 m·min^{-1}) 5-minute periods, but no difference was evident between the subsequent and average HIR. Likewise for the effect of time periods on static exertions (F = 1,811.4, $P < 0.0005$) and the post-hoc comparisons of the three means (peak static exertions = 3.74, subsequent static exertions = 1.0, and average static exertion = 1.3). Significant time periods x positional groups interactions for both HIR (F = 3.2, $P < 0.0005$) and static exertions (F = 25.7, $P < 0.0005$) were evident. Post-hoc analysis of these revealed significant ($P < 0.0005$) reductions in HIR succeeding the most intense period of play (compared to the match average) for the inside (-23%) and outside (-20%) back positions (Figure 6.9), and significant (P < 0.0005) reductions in the number of static exertions in the front row (-21%), back row (-24%) and outside backs (-46%) positions following peak periods of static exertion involvements (again, compared to the match average) (Figure 6.10).



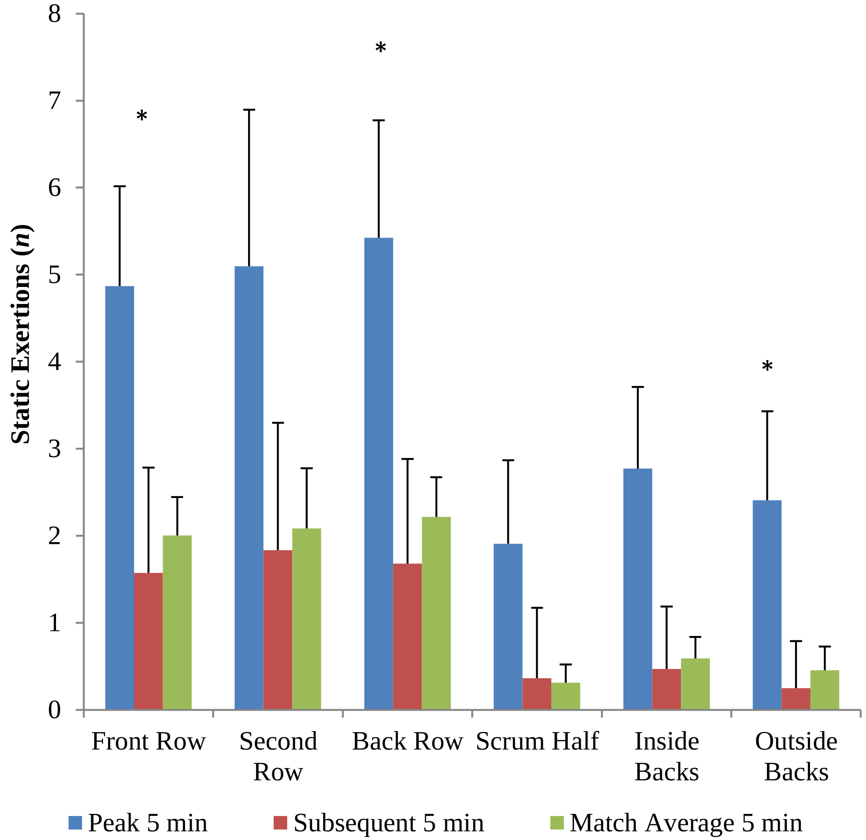


Figure 6.9 Peak, subsequent and match average 5-minute HIR for different playing positions. *subsequent 5-minute period differs significantly from average 5-minutes.

Figure 6.10 Peak, subsequent and match average 5-minute static exertions for different playing positions.*subsequent 5-minute period differs significantly from average 5-minutes

6.4 Discussion

The current investigation is one of the first to identify changes in physical demands across elite rugby union matches using short (~ 5-minute) time periods. This analysis has revealed notable movement changes throughout match play. More specifically, changes in HIR and indeed LIR, indicated that there was a marked reduction in physical performance towards the latter stages of a match, whilst for some positions (i.e. inside and outside backs) there was a distinct temporary decline in HIR following the most intense periods of the game. Positional group differences were seen in the number of static exertions over the course of a match, and as with HIR, there was also evidence of a 'transient' reduction in the number of these following intense periods of play for certain positional groups (i.e. the front row, back row and outside backs).

The current observation of the greatest total distances ($m \cdot min^{-1}$) generally occurring in the initial five minutes, accompanied by a concomitant reduction in distance covered in the latter stages of the match, is somewhat in contrast to previous studies which have reported that distance covered does not decrease from the first to the second half of a rugby union match (Duthie et al., 2005; Cunniffe et al., 2009). However, this finding is in agreement with those of Roberts et al. (2008), who reported greater distances were travelled in the opening 10 minutes of elite rugby union match play compared to 50 - 60 minutes and 70 - 80 minutes. Interestingly, Roberts et al. (2008) attributed the change in distance covered over the course of a game to a reduction in low-intensity running, as changes in HIR in their study (~ 35 m in 10 minutes) were not significant. However, Jones et al. (2015) recently reported significant declines in both LIR and HIR across 10 min periods of rugby union matchplay. Significant reductions in LIR were evident in the present study, with a progressive decline displayed, in conjunction with decreases in HIR in the latter stages of the match across positions, suggesting that a reduction in HIR can, in part, explain some of the reduced distance covered over the course of a rugby match. The observed reduction in HIR in this study (in the second half ~ 35%) is in agreement with findings from other team sports such as soccer (Bradley et al., 2010; Bradley & Noakes, 2013; Mohr et al., 2003), rugby league (Waldron et al., 2013), and Australian rules football (Aughey, 2010). Thus, this decline appears to be a consistent pacing strategy employed within team sports and is thought to be strongly associated with the management of fatigue occurring in the latter stages of a match. This fatigue has primarily been attributed to a significant depletion of muscle glycogen (Bangsbo, Mohr & Krustrup., 2006; Krustrup et al., 2006), dehydration (Edwards & Noakes, 2009) and associated hyperthermia. Whether such mechanisms can explain the decline in HIR in the present study is speculative. However, Cunniffe et al. (2009) reported that rugby union is played at ~ 80% of an individual's maximal oxygen uptake, an intensity which predominantly requires the transfer of energy from muscle glycogen as a substrate (van Loon et al., 2001), and which is similar to other team sports where significant glycogen depletion is observed (Krustrup et al., 2006). Accordingly, it seems likely that rugby union places a significant demand on players' endogenous carbohydrate stores, which might, to some extent, explain a decline in HIR towards the end of a match. Whilst not significant, it is notable that this decline was smallest for the inside and outside backs positional groups (~ 23 – 29%), and largest for the second row (~ 62%). It is unclear whether such a pattern of movement reflects the tactical requirements of these different positions, or indeed the different physiological qualities and capabilities (such as aerobic capacity) of the players who play in them (Duthie et al., 2003). Nonetheless, these findings provide information on the potential decline in HIR experienced by different positional groups, and thus can be used to optimally condition players and potentially inform substitution strategies.

There were observed differences in the number of static exertions between positional groups, which are in accordance with previous studies that have shown that forwards are involved in a greater number of static exertions than backs (Cunniffe et al., 2009; Duthie et al., 2005; Roberts et al., 2008). However, there were significant declines evident in the number of static exertions taking place over the course of the match, specifically towards the end of the first half and for the majority of the second half. This was similar to the findings of Jones et al. (2015) who reported contact frequency decreased significantly from 50-60, 60-70, 70-80 minutes when compared with 40-50 minutes of match play, although between no other periods. The current findings however are in contrast to Roberts et al. (2008), although they reported no change in the *time* involved in static exertions over the course of a match rather than the change in *number* of static exertions. Again, the precise cause for the change in static exertions in the present study is speculative, but reasons could include tactical requirements of the game and/or the development of fatigue as previously discussed.

It is worth noting that only the number of static exertions was measured in this study, rather than the intensity of the static exertion, which might reflect better the influence of fatigue on this parameter. Indeed, it is possible that the number of static exertions that players engage in reflects a decision that players make to be involved in these physiologically demanding actions (Johnston & Gabbett, 2011). This would tally with proposed theories of pacing in team sports, whereby players are thought to distribute their efforts in order to have exercised vigorously throughout the match without causing severe damage to peripheral physiological systems (Edwards & Noakes, 2009). In this context, it is possible that fatigue, associated with muscle glycogen depletion, for example, might inform players' pacing strategies across the game (including the distance they cover, the HIR they do and the number of static exertions they involve themselves in). Few studies have yet to consider the nature of pacing in rugby union. This study would appear to show that the pacing strategy adopted in rugby union is somewhat similar to that adopted in other team sports such as soccer (Bradley & Noakes, 2013; Carling & Dupont, 2011; Mohr et al., 2003) and rugby league (Waldron et al., 2013).

That is, there is a slow and progressive decline in distance covered and HIR (and indeed static exertions) for players who play in the whole-match. It is interesting to note that there appeared to be an 'end-spurt' in the number of static exertions in the final 5-minute period of the match. This phenomenon is common in the study of pacing (Albertus, Tucker, St Clair Gibson, Lambert, Hampson & Noakes, 2005; Tucker & Noakes, 2009; Tucker, Rauch, Harley & Noakes 2004), and is thought to be due to the uncertainty of the exercise duration being reduced as the exercise end-point approaches, thus allowing players to utilise a 'metabolic reserve' which has been kept for the duration of exercise to prevent a catastrophic disturbance of homeostasis (Tucker & Noakes, 2009). Indeed, playing duration has a marked impact on the pacing strategy adopted in rugby league (Waldron et al., 2013). That is, interchanged players, who play for a shorter period of time, are willing to exercise at a higher intensity than those who play for a full match. Future studies may wish to consider whether different pacing strategies are employed in rugby union in replacement players (who will play for a shorter duration), and whether knowledge of the exercise duration has a significant influence on how rugby union players pace their efforts. Such studies will provide further information on the determinants of fluctuations in physiological exertions observed in the present chapter.

This study was also the first to consider the influence that 'peak' periods of play have on match performance in rugby union. Peak HIR in a 5-minute period ranged between 23.16 and 26.68 $m{\cdot}min^{-1}$ across all positional groups, and was followed by a 23 and 20% reduction in HIR in the subsequent 5-minutes for the inside and outside backs, respectively (compared to their match average HIR $m{\cdot}min^{-1}$). This decline is in accordance with previous findings in soccer, where decrements in HIR have been shown to range between 15% (Di Mascio & Bradley, 2013) and 50% (Bradley et al., 2009) in elite soccer players following the most intense sections in the game. This has been termed 'transient fatigue', and is potentially associated with reduced muscle phosphocreatine content (Mohr, Krustrup & Bangsbo, 2005) and disturbances in muscle ion concentration (Mohr et al., 2005). It is not clear why such a decline in HIR was not evident for the forwards, however they (barring the second row) did show a decline in the number of static exertions they engaged in (by 20 - 45%) following a peak 5-minute period. Such a finding might reflect the more intense nature of static exertions for the forwards, and indeed more intense HIR for the backs, yielding more pronounced fatigue. However, this finding might also be related to the pacing strategy adopted by individual positional groups. It has previously been proposed that team sport athletes pace their efforts at the micro-level (Edwards & Noakes, 2009), which involves dynamically altering the intensity of exercise (within the overall pacing schema) to account for particularly intense periods of play. Accordingly, it may be that forwards transiently reduce the number of static exertions they are involved in to maintain match performance, whereas backs reduce the amount of HIR they perform. It should be noted that utilising predetermined periods of 5-minutes to assess changes in movement may have influenced the results in the present study. That is, a recent investigation in elite soccer players (Bradley & Noakes, 2013) reported a decline in HIR due to the ball being out of play (which reduced the opportunity for HIR) and thus proposed the use of 'rolling' periods in data analysis that account for the ball in and out of play. Considering the game of rugby union is not continuous in nature, with numerous stoppages when the ball is out of play, such approaches would appear prudent for future work.

6.5 Practical Applications

The findings predominantly demonstrate a slow and progressive decline in distance covered, LIR and indeed HIR throughout match play, suggesting evidence of fatigue is present in elite rugby union players and that they adopt a pacing strategy that is similar to many other team sports. In contrast, players were generally able to maintain the number of contacts they were involved in throughout the match. This information could be useful in aiding practitioners to implement the most effective replacement strategies that enable the maintenance of high intensity running across the team. For example, the results display the greatest decline in HIR occurs in the front row, second row and scrum half positions. Therefore, making replacements to these positional groups at the onset of fatigue could potentially aid in maintaining higher intensities throughout the duration of the game, albeit subject to situational factors and individual ability. Given the association observed between HIR and aerobic capacity in other team sports (Johnston et al., 2014b; Krustrup et al., 2005) and the observed decline in HIR in the present study, it would also appear prudent to maximise aerobic capacity in rugby players to ensure maintenance of HIR.

The 'peak' periods elicited greater intensities than have been previously reported for the average match demands. Conditioning practitioners can use these results to devise training programmes to prepare players for the most intense periods of the game and thus increase their ability to cope with such stresses throughout the game. Transient changes in HIR and static exertions were evident during matches, with the forwards appearing to sacrifice the number of static exertions they were involved in after a 'peak' period, whilst the same was true for HIR amongst backs. This information has important implications for conditioning practices in rugby union. For example, specific game conditioning programmes, designed to maintain high intensity effort immediately after 'peak' periods may help to improve players ability to sustain intensity levels (or at least reduce the decrement in intensity) following 'peak' periods. The present study suggests that, for backs, drills which incorporate HIR at approximately 25 $m \cdot min^{-1}$ are appropriate, whereas for forwards approximately 6 contacts per minute should take place to condition for worst case scenarios.

6.6 Summary

In conclusion, the present study has demonstrated reductions in total distance covered, LIR and HIR in the second half of match play compared to the first. It was illustrated that distance covered, HIR and static exertions fluctuate over the course of a rugby union match. These changes appear to vary, to some extent, depending on positional group, but in the main there is a slow and progressive decline in work done which is consistent with changes observed in other team sports. Such information may be used, amongst other things, to inform replacement strategies and inform training programmes to aid in preparing rugby union players most appropriately.

Chapter 7: General Conclusions

7.1 Overview

The programme of research reported in this thesis has collated and assessed the largest multiple team data set in elite rugby, to present innovative and original findings that enhance our understanding of the game at this standard. Through the combined use of GPS and video analysis, the four studies of this thesis have provided a comprehensive analysis of the match demands relative to the English Premiership. It has sought to extend our understanding of locomotive (Chapters 3 & 4), performance-related (Chapter 5) and fatigue and pacing aspects of match play (Chapter 6), which thus far, has been relatively limited in the sports science literature, particularly in relation to individual positions.

The first study highlighted the shortcomings of utilising absolute speed classifications for quantifying locomotive variables, which has been the practice in most previous related research. Studies two and three established locomotive and performance-related profiles for three positional groupings of players, and the fourth identified movement changes throughout the course of match play and explored whether these reflected the development of fatigue and/or the employment of pacing strategies. The following sections present an overview of the key findings from the programme of research, an acknowledgment of the pertinent limitations, the practical implications of the findings, and suggestions for further research.

7.2 General Discussion

Across team sports analysis, authors often refer to the limitations that are apparent when speed classifications are defined through the use of absolute arbitrary zones. Yet, whilst concerns have been acknowledged, few have endeavoured to advance or even investigate these methodologies. Indeed the findings in Chapter 3 demonstrated that the selection of speed classifications for locomotive analysis of rugby union players could be crucial for the interpretation of the data as the findings identified that varying individual running capabilities were present across the 15 positions, thereby posing the question as to whether it is appropriate of use a singular classification of absolute speed thresholds in determining locomotive movement patterns across individual positions. The findings of Chapter 3 are one of the first to examine to what extent applying different speed classifications has on the interpretation of the data. It was found that the selection of speed thresholds can be critical as the findings illustrated that the distances travelled per match in HIR and sprinting can vary by as much as 749 m and 408 m, respectively, depending on the classification adopted. The findings actually reinforced those of others (Abt & Lovell, 2009; Lacome et al., 2014) which identified that the use of Venter et al.'s (2011) approach of employing individualised speed classifications generated typically lower values for HIR and sprinting than the absolute zones most often cited and currently favoured. Indeed, the overall average HIR speed classification determined in Chapter 3 (15.13 $km \cdot h^{-1}$) (using the methods employed by Venter et al., 2011) was similar to that identified when physiological measures were used to ascertain HIR speed (Abt & Lovell, 2009; Lacome et al., 2014). Whilst the study acknowledged the use of physiologically-determined individual speed classifications would be preferable, obtaining such measurements amongst elite level professional team sports players is very impractical. Notwithstanding the limitations of the approach taken, the findings of this chapter have provided evidence of the large discrepancies in using an array of speed classifications to investigate rugby union. It has emphasised the degree to which the selected speed classifications can influence the interpretation of data, which has seldom been done before. It further demonstrated the use of % Vmax as an appropriate alternative method to investigate rugby union locomotive patterns as it accounts for individual capabilities.

Chapter 4 and Chapter 5 presented the locomotive movement patterns and performance related efforts of elite rugby union players from one of the largest data sets of its kind. To the author's knowledge, it is the only study to present a comprehensive analysis of the English Premiership, which is essential in order to prepare top-level players appropriately for competition. The findings of Chapter 4 and 5 reinforced previous studies (Coughlan et al., 2011; Cunniffe et al., 2009; Deutsch et al., 2007; Duthie et al., 2005; Jones et al., 2015; Roberts et al., 2008) that for the most part, rugby union is predominantly played (~ 80%) at low locomotive intensities intermittent with static exertions. The backs were identified as covering greater distances than the forwards in both absolute (6,134 m and 5,221 m respectively) and relative terms (67.9 m·min^{-1} and 60.9 m·min^{-1}, respectively). Whilst Lacome et al. (2014) suggested that the lower distances covered by the forwards reflected their inferior aerobic capacities (in comparison to the backs), the observations in Chapter 5 indicate that as a group they were involved in the greatest frequency and longest static exertions, occurring primarily at the ruck. Thus, supporting the notion that the forwards' primary role is to build platforms and contest for the ball at the breakdown, ultimately aiming to win and secure possession (Bompa & Claro, 2009; Deutsch et al., 2007; Eaton & George, 2006).

In addition to the traditionally grouped playing positions, the findings have uniquely presented information on individual playing positions from across the English Premiership. The findings have highlighted that substantial positional differences were evident in both locomotive and performance-related aspects of match play, which have rarely been identified previously. The scrum half position was identified on average to cover the most distances (~ 6.600 m and 74.2 m·min^{-1}) and the tighthead prop the least across all positions (~ 4,300 m and 58.3 m·min^{-1}). The results revealed the back row positions significantly differed from the front and second row, particularly in the distance covered, with notably superior distances covered whilst striding (HIR) (as much as ~ 250 m) and "sprinting" (44.7 m), which were most similar to the inside centre in locomotive movement patterns.

It was highlighted, in conjunction with their greater distances identified in Chapter 4, that the flanker positions were involved in the most static exertions (~ 46 - 48), primarily owing to their higher occurrences of tackles (on average ~ 12 per match) and incidences of high intensity exercise bouts (~ 3 per game), which, albeit notably less than previous findings (Austin et al., 2011a; Jones et al., 2015), support the theory that the back row positions tend to remain on the periphery of the breakdown and act as the defensive or offensive line. What is interesting, however, is that the number 8 position (Chapter 5) carried the ball most frequently in matches (~ 11 per game) demonstrating their hybrid role and the versatility required in this position, which has seldom been documented in the English Premiership previously. Similarly, individual analysis helped determine that the outside backs, were characterised by their attainment of higher peak speeds (average of 31.3 $km \cdot h^{-1}$), with the wing positions specifically reaching the highest speeds (31.4 – 31.5 $km \cdot h^{-1}$), which in accordance with Quarrie et al. (2013) would be expected as they are believed to use their quicker pace to beat their opposition in achieving territorial advancement. The findings of Chapter 5 further substantiated this as the outside backs were illustrated to carry the ball the most often (within the backs positions), typically 7 times per match, with a trend identified as the wing positions to score more tries, thus corroborating the claims that the backs continually seek space to enable them the 'play' the ball (Bompa & Claro, 2009; Deutsch et al., 2007; Eaton & George, 2006).

However, in contrast to previous findings, distinctively few significant differences between positions were evident at the speeds of sprinting, particularly when maximally sprinting. Whilst the fly half and right wing positions covered the most (~ 70 m and 64 m, respectively) the distances reported for sprinting were notably lower than previous GPS investigations

(Coughlan et al., 2011; Cunniffe et al., 2009) and indeed video based TMA (Eaton & George, 2006; Roberts et al., 2008). Whilst, this is most likely a reflection of the relative speed thresholds applied in the current investigation which as demonstrated in Chapter 3 and discussed earlier, can elicit large discrepancies when likened to absolute speed classifications. Yet it is conceivable that this alternative approach has identified misinterpretations of movement patterns in earlier work and further recognises the essential need to determine standardised individualised speed classifications for use in rugby union (Lacome et al., 2014; Reardon et al., 2015) to corroborate such findings.

Moreover, this is one of the few investigations to include the scrum half position for examination owing to its perceived 'unique' role within the game, epitomised as the link between the forward and back positions. In addition to the findings of Chapter 4, the analyses in Chapter 5 supports the uniqueness of the scrum half in their dominance in passing throughout match play and their infrequent involvement in the breakdown of rucks. Typically they are involved in as much as 50% of total team passes during the game, thus ensuring their availability to distribute the ball when required. Additionally, little data exists on the fly half position on its own. However, in alliance with the inside centre positions, they were involved in the most tackles (~ 9) amongst the back positions (which to-date has rarely been seen), and possibly could be owing to their involvement in the kick-chase element of the game and thereafter being the first line of defence.

Whereas Chapters 4 and 5 have provided new and often unique data on the general (average) demands of the contemporary game and the primary individual roles of elite rugby union players participating in the English Premiership, to the author's knowledge the findings in Chapter 6 additionally provide a novel insight into locomotive movement patterns. It identified the potential need for game analysis to be broken down into shorter time periods (~ 5 minutes) to elicit a better understanding of the peak match demands and the fluctuations in positional demands throughout a whole match. As in Chapter 4, Chapter 6 revealed that the scrum half and front row positions produced the greatest and least relative (peak) distances; as much as ~ 40 $m{\cdot}min^{-1}$ more than reported during the average match demands. In this way, it provided information on locomotive movements demands for the most intense scenarios (for both distance and HIR) and indeed static exertions, which could be essential knowledge when devising schedules for practitioners. However, so far little attention has been given to the magnitude of fatigue experienced by players during competition, or if indeed any pacing strategies are adopted. Chapter 6 clearly identified both locomotive movement and static exertions alter throughout the course of a game, primarily observing that distances were greatest in the initial 5- minutes of play (in accordance with Jones et al., 2015; Roberts et al., 2 008), and thereafter a subsequent decline towards the end of match play. In part this was attributed to a decline in HIR, which contradicts the earlier suggestions of Roberts et al. (2008) that the decline was ascribed to a reduction in low intensity running and reflective of fatigue. Indeed, it appears the findings in Chapter 6 are the first to highlight that elite rugby union players employ pacing strategies representative of other team sports, such as rugby league (Waldron et al., 2013), with a successive decline in HIR following the initial part of play. This might be useful for informing substitutions and replacements of players and positions. Moreover, a further innovative finding of Chapter 6 was, in line with other team sports (Bradley & Noakes, 2013; Mohr et al., 2003), that positional 'transient fatigue' was experienced by elite rugby union players. Principally this was highlighted by the inside and outside backs demonstrating temporary fatigue in the unsustainability of HIR following 'peak' efforts, whereas marked reductions in the frequency of static exertions were evident for the front and back row and also outside back players following peak exertions. This in part could explain the reduction in both locomotive movement (Chapter 4) and static exertions (typically the frequency of rucks, Chapter 5) of the prop positions, in particular the tighthead, supporting anecdotal suggestions that the heavy loads sustained in the scrum cause a reduction in activity. On this basis it is proposed that either players suffer temporary fatigue following intense periods of play during competition, or adopt pacing strategies at the micro-level (Edwards & Noakes, 2009). This is worthy of consideration with respect to training scenarios and highlights the need in some instances to train players whilst they are in a fatigued state in order to facilitate their ability to cope under such stresses during competition.

7.3 Limitations

At the outset of the current research the GPSports SPI Pro 5 Hz GPS device was the most sophisticated available. However, whilst it has been shown to have acceptable validity and reliability over long durations and at moderate speeds, over shorter distances (< 20 m) and higher running speeds (> 20 $km \cdot h^{-1}$), these qualities have been questioned (Petersen, et al., 2009). Moreover, during the past four years further developments in GPS technology have produced devices capturing data at rates of 10 Hz and 15 Hz (see Chapter 2), enhancing their validity and reliability, although still highlighting discrepancies at higher running speeds (Johnston et al., 2014). Whilst it is acknowledged that the use of these (for the third season's data) would have improved the quality of the data produced, for the sake of consistency the 5 Hz devices were retained throughout.

The current investigation is distinctive in that it has utilised a relatively large sample of elite level rugby union players, but a cost of being permitted access to such players was a restricted degree of direct control the investigator had over the design and its procedures. For example, whilst concerns have been identified over the *inter-unit* accuracy of GPS device (Duffield et al., 2010) and their interchangeability, owing to financial restrictions on some

Premiership clubs, limited numbers of GPS devices were available and units were interchanged across numerous players over the course of the research. In addition, the selection of the players (and their positions) who wore the GPS units was out of the researcher's hands, thereby restricting their influence over the balance of the sample sizes across clubs and positions, and the number of matches played by each player. Furthermore, while the intention was to explore the physical demands of the game, it is recognised that no direct physiological measurements were taken. Such data would have enriched the analysis (primarily in the identification of high intensity running thresholds), but it was not possible owing to the diversity of the training programmes and strategies adopted by the different clubs, and the impracticalities that this created.

7.4 Practical Applications

The current findings have provided a comprehensive and contemporary analysis of elite rugby union when participating in the English Premiership. The findings of Chapter 3 have highlighted the extent to which the selection of speed classifications can influence the interpretation of the data. It is conceivable that these findings could be utilised by practitioners to help make informed decisions on the most appropriate methods to use when determining speed classifications zones. Across the three subsequent investigations (Chapters 4, 5 & 6) a number of novel findings have also been identified, one being that the physical demands (i.e. locomotive and performance-related demands and static exertions) differs depending on individual and positional groups. Therefore it follows that coaches should devise bespoke training and recovery schedules (per playing position) to account for such variation. The studies within this thesis provide practitioners with objective data based on the average locomotive demands, performance-related demands and the fluctuations of match demands when analysed in smaller time periods. Such findings consequently provide practitioners with information needed to aid in the construction of conditioning programmes, as it enables sessions to be created that can replicate, overload or reduce match stimuli to ensure players are optimally trained for competition. Having access to this data, which is based on numerous teams across the English Premiership, allows coaches to have a more objective understanding of match demands across all aspects of the game and therefore should be highly beneficial for preparation purposes.

A prominent finding was that the identification that ‘peak’ demands could be much greater than those indicated by the average match demands, providing practitioners with essential (and novel) information on the possible most intense scenarios per positional group. These discoveries can therefore be utilised to adapt training to ensure that players are capable of coping with such high demands during competition, which might have the added effect of reducing elements of fatigue towards the latter aspects of matches, or indeed transient fatigue throughout. As it was highlighted that fatigue is potentially reflected in a reduction of static exertions, predominantly for the front and back row positions, and in HIR for the inside and outside backs, practitioners may also benefit from including training sessions when players are in a fatigued state that focus on performance-related skills and techniques. Alternatively (or additionally), such information could be utilised to identify when a reduction in intensity typically occurs and hence used to inform replacement and substitution strategies, albeit other tactical aspects and situational variables may play an additional part in the decision making process.

As the data were collected from a number of teams belonging to one league, it is suffice to infer these findings represent the average match demands of the English Premiership. Therefore an additional application of the findings is to be used as a comparative measure across different leagues, levels of competition (e.g. domestic versus international), age groups (junior versus senior) and importantly as a reference to help devise return to play protocols. Given the high incidence of injuries in the English Premiership (Brooks et al., 2005), with as many as 19% being re-occurrences (Brooks et al., 2008), the findings from the current investigation could, arguably, also be instrumental to clinical practitioners in the design of return-to-play protocols (Reid et al., 2013). Knowledge of the locomotive and performance-related demands could be used as an objective benchmark for guiding the recovery process, particularly in light of the pressure that such practitioners are often under to rehabilitate players back to match fitness as quickly as possible, and the possibility that this can be too soon, heightening the risk of injury re-occurrence.

Alongside the recommendations noted above and in Chapters 3-6 of how these findings can be utilised in practical terms (i.e. ‘in the real world’), the data has already been applied by numerous practitioners, coaches and officials to help with the designing of training programmes and player competition preparation. Two examples are: 1) Chapter 3 identified large discrepancies were evident in the findings when different speed classifications were used and indeed the potential misinterpretation of the data when using absolute, arbitrary speed classification zones. Following such results several clubs adopted speed classifications based on individual abilities, albeit not necessarily determined in the same manner described in this thesis. 2) Based on the findings of Chapter 4, which highlighted that the locomotive demands are typically less for the forwards than the backs positions, particularly the front and second row positions, some clubs amended their pre-season testing protocols for the forwards positions (particularly the front row) by reducing the distances covered in their aerobic effort test in comparison to the backs to better reflect the demands of the game.

Moreover, the results from across the thesis have also been used for comparative purposes. The findings have been used to compare domestic match demands in the English Premiership with the match demands at the international standard. Coaches and practitioners have used this knowledge to gain a greater understanding of the disparities between the two standards, with a particular interest in the locomotive movement patterns. Comparing the two provided practitioners with objective information on the typical weekly demands players sustained whilst competing in the Premiership. This was then utilised to deduct whether firstly it mimicked the demands at the international standard and most beneficially, to help in structuring appropriate conditioning programmes for players once they arrived for international duty.

Furthermore, over the last couple of years, governing bodies have been trialling the use of artificial surfaces for alternative terrain to compete on. Whilst no statistical analysis were performed, the locomotive average demands during match play on grass were compared to those on artificial turf to determine if there were any notable differences in playing position demands when competing on the two different surfaces. The findings were therefore used to help provide objective information to aid in future decisions regarding playing surfaces.

In addition, the findings from Chapters 4, 5 and 6 will be used in the future as a marker to aid with the development pathways for potential elite rugby union players.

7.5 Future Directions

The introduction of GPS has enabled researchers and sports practitioners to analyse competition and training with relative ease, allowing simultaneous, instantaneous (real time) and post-match analysis to be conducted. Hughes and Barlett (2002) suggested knowing the average demands of the competition one is involved in is essential for preparation purposes, and whilst the current research reflects some of the first (to use GPS technology) on this scale to provide data of the contemporary game at the elite level, there remains scope for investigations into applying such knowledge in a training and performance context.

The benefits of understanding match demands are to allow practitioners to devise informed training programmes that elicit physiological and muscular adaptations to deal optimally with the stressors of the game. Whilst the present research has provided information on the competitive environment, in order to determine whether training is having the required effect and understand how individuals respond to different stimuli, monitoring of training and individual adaptations in concurrence with competition is required. This will allow better informed training modifications to be made and ultimately enable athletes to make the necessary adjustments to their training regimes. This is particularly pertinent as previous research monitoring training loads via GPS has identified that the match demands were not met, and that the training methods employed were not as intense or demanding as required for competitions (Hartwig et al., 2011). Indeed, the game of rugby union is multifaceted in nature in comparison to individual sports (Duthie et al., 2003), as are all team sports, and research has highlighted that its match demands are variable and susceptible to a variety of factors (Gabbett, 2013a; 2013b; Rampinini et al., 2007b; Vaz et al., 2011), such as winning and losing, the score of the game, the level of opposition, attack or defence, or home advantage. Whilst such situational analysis has taken place in other team sports, including soccer and rugby league, little attention has been given to how such external factors can impact on the match demands in rugby union, and thus it should be considered in the future.

The present thesis has predominantly offered information on players who start matches and their typical movements and actions. However, research across other team sports has identified varying profiles of substitute and interchange players to those who are in the starting line-up, often reporting that they play at higher intensities (Bradley & Noakes, 2013;

Waldron et al., 2103). Currently, it is unknown how time on the pitch can alter positional playing profiles and the impact made by both substitution and replacements players. Following the findings of Chapter 6, a further analysis of the role of substitution players would provide insight not only into quantifying the decline of effort or pacing strategies employed by starting players, but also the intensities demonstrated by such players and their effects on match play.

Finally, rugby union is reported to have a high incidence of injury (Brooks et al., 2005; Garroway et al., 2000), which is often associated with the contact elements of the game. However, to-date, whilst the frequency and duration of contacts within match play have been identified, an assessment of the magnitude of such efforts has been prohibited. With the recent advancements in GPS technology and the inclusion of tri-axial accelerometers and gyroscopes, such devices have the potential to provide information on the extent of collisions. Such information, coupled with training load and competition monitoring, could be imperative for practitioners to identify optimal training and recovery processes for individuals, and even possibly help in the reduction of the number of non-contact and re-occurrence injuries that are particularly prevalent in the English Premiership (Brooks et al., 2005, Brooks et al., 2008; Brooks & Kemp, 2011).

The research embedded within this thesis has significantly advanced our understanding of the elite game, providing ‘typical’ positional-related data and insight into ‘worse case’ scenario elements of locomotive and static exertions. It is hoped that such findings can have direct implications for practitioners in aiding the development of optimal training regimes for competition.

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Appendices

Appendix 1. Ethical Approval

University of Chester
Faculty of Applied Sciences
Research Ethics Committee

Tel 01244 511740
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Nicola Cahill
Department of Sport and Exercise Sciences
5th Floor, Price Tower
University of Chester
Parkgate Road
Chester
CH1 4BJ

10th November 2010

Dear Nicola,

Study title: **The Demands of Training and Playing in Elite Rugby Union.**
FREC reference: **473/10/NC/SES**
Version number: **1**

Thank you for sending your application to the Faculty of Applied Sciences Research Ethics Committee for review.

I am pleased to confirm ethical approval for the above research, provided that you comply with the conditions set out in the attached document, and adhere to the processes described in your application form and supporting documentation.

The final list of documents reviewed and approved by the Committee is as follows:

Document	Version	Date
Application Form	1	September 2010
Response to the FREC request for further information and clarification	1	November 2010
Participant Information Sheet	2	November 2010

With the Committee's best wishes for the success of this project.

Yours sincerely,

Simon Alford
Chair, Faculty Research Ethics Committee

Enclosures *Standard conditions of approval.* *C.c. Supervisor/FREC Representative*

Appendix 2. Participant Information Sheet

The Demands of Training and Playing in Elite Rugby Union

You are invited to take part in the research project titled above. Outlined below are the details of the project. Please read the details carefully so you can make a fully informed decision whether or not to participate. If you have any further queries please do not hesitate to contact me, details of which are provided below.

Thank you for taking the time to read this information.

What is the purpose of the study?

The purpose of the study is to use global positioning systems (GPS) to collect data on elite rugby union players across participating clubs in the Aviva Premiership, with the predominant aim to evaluate the utility of GPS devices as a monitoring tool in professional rugby union. It aims to establish a greater in depth understanding of the physical demands position specific of rugby union players, through the data collected by the GPS units.

Why have I been chosen?

You have been chosen because you are a player of a Premiership rugby union club.

Do I have to take part?

It is entirely your own decision whether to take part or not. Taking part will require you to sign a consent form giving your full permission to participate, but can be withdrawn without reason at anytime during the season. If however, you do not participate it will not hinder your performance or team selection in any way.

What will happen to me if I take part?

By taking part you will be consenting to wear a GPS (SPI Pro; GPSports Systems) unit encased within a protective harness between the shoulder blades in the upper thoracic-spine region along with a heart rate monitor belt during training and competitive matches throughout the season. Furthermore, you will be consenting to play with your teammates and opposition wearing GPS devices and for the data collected by the GPS on your performance to be used in the study.

Five minutes prior to exercise the GPS unit and heart rate monitor will be fitted to you and turned on and off at the end of the session. Following the session the GPS unit will be returned to the nominated person in your club.

Data collected by the GPS on your performance will be downloaded onto a computer and the raw data will be forwarded to the PhD research student confidentially. Full anonymity of all players will be preserved at all times.

What are the disadvantages and risks?

Please see GPS Injury Risk for Players (attached).

What are the benefits?

Taking part will allow all parties involved to gain superior knowledge of the physical demands required for specific positions in elite rugby union. It will enable researchers and practitioners to design individualised training programmes to maximise a player’s development. Moreover, it will permit practitioners to prepare players with greater accuracy for the stresses and strains put on the body during a competitive match.

What if something goes wrong?

If you are to become injured taking part in this study or as a direct result of wearing a GPS unit, your insurance is not affected in anyway. Both Rugby Care and Joint Professional Players Insurance (JPI) are unaffected by the use of GPS in matches.

If you wish to complain or have any concerns about any aspect of the way you have been approached or treated during the course of this study, please contact Professor Sarah Andrew, Dean of the Faculty of Applied and Health Sciences, University of Chester, Parkgate Road, Chester, CH1 4BJ, 01244 513055.

What use will be made of the results?

Results of the data may be published in the future but any data included will in no way be link to any specific participant, with ***complete anonymity and confidentiality guaranteed.***

All your data will be stored on a secure password protected server which you and members of your club will have access to, to use as you please. No data will be exchanged across clubs at any point during or after the study.

All raw data use in the study will be securely stored for 10 years, after which it will be destroyed.

Who is organising and funding the research?

The Department of Sport and Exercise Sciences at the University of Chester along with the Rugby Football Union (RFU) and the English Institute of Sports are responsibility for jointly organising and funding this study.

Who may I contact for further information?

If you have any questions about the project, either now or in the future, please feel free to contact Nicola Cahill via the Department of Sports and Exercise Sciences, Tel: 01244 511848, n.cahill@chester.ac.uk

Thank you for your interest in this research.

INJURY RISK ASSOCIATED WITH GPS TECHNOLOGY IN RUGBY

1. On 26 May, the RPA board sought the following assurance in relation to the PhD study into the use of GPS technology in the Aviva Premiership:

   "The players (should be) made fully aware of the potential risks of wearing the GPS monitor. We appreciate a player education process would form part of them signing the necessary consent forms."

2. This document has been drafted accordingly and comprises three components:
   1. The shared opinion of: Dr Simon Kemp, RFU head of medicine and Mr Andy Smith, the Aviva Premiership medical adviser;
   2. An email dated 29 November 2009 from Mr Richard Nelson, Consultant Neurosurgeon, to Dr Simon Kemp;
   3. An email letter dated 7 March 2010 from Kevin Lidlow, the RPA physiotherapy adviser, to Professor James Frame, formerly the RPA representative on the Professional Game Board Medical Advisory Group.
3. The SpiPro monitors for use in the study weigh 76gm and measure 87mm x 48mm x 20mm. They are worn in a padded harness between the shoulder blades, broadly in line with T2 – T6 vertebrae.

Dr Simon Kemp and Mr Andy Smith

4. Dr Kemp and Mr Smith have concluded that the benefits of the proposed study are significant, the risks negligible and therefore it has their full support, taking into account:
   1. The absence of any reported injuries directly attributable to GPS monitors from games of rugby union for which dispensations have been granted nor from other contact sports wherein they have been worn, e.g.:
      i. The Australian Football League (AFL) allowed use of GPS units in 2005. GPS units have been worn in more than 1,000 AFL games since 2005;
      ii. In May 2009 the National Rugby League in Australia (NRL) approved the use of GPS units in games, following an incident-free four week trial. Up to 10 players in each of 13 NRL teams wore units for 20 rounds of competition;
      iii. The England rugby league team used GPS monitors during their four-nations tournament in October 2009.
   2. The absence of any serious injuries sustained to the thoracic region as a result of a blow or other collision by England or Premiership players since the beginning of the England Rugby injury and training audit in 2002.
   3. The cushion of padding, muscle and other robust soft tissue between the vertebrae of the thorax and the GPS monitor.
   4. The natural recess formed by the shoulders in which the GPS monitor sits.
   5. The possibility that in the event of a blow of sufficient magnitude to damage the thoracic structure, a monitor whose surface area is $42cm^2$, would be a positive benefit, as a vehicle for dissipating the force of the impact.

Mr Richard Nelson

“Wearer

1. The GPS unit will be positioned over the upper thoracic spine in the midline between the scapulae lying over the major interscapular and paraspinal muscles. In 20 years of managing spinal disorders in professional rugby players I am not aware of any significant skeletal or spinal cord injury at this level as a result of direct contact.
2. It is conceivable that a direct blow to the GPS could be transmitted to the back causing muscle contusion and/or a fracture of the thoracic spinous processes at that level. But on balance I think it more likely that the unit would dissipate the impact of a hard structure such as head, elbow, knee or boot and if anything provide a minimal degree of protection.

Opposing player

1. It is possible that an opposing player would impact the GPS with a hard structure as above. However, the unit is not rigidly constrained and again I suspect the forces would tend to be dissipated through the soft tissues of the spine rather than concentrated in a way that would increase the chances of injury.
2. I cannot identify any indirect risks to players of wearing the GPS unit.

In summary I would support the RFU in this interesting and potentially useful project. I do not feel there is any need to take special precautions.”

Mr Kevin Lidlow

“Dear Jim

Further to our discussion on Saturday I would ask that you make an inclusion to the agenda item on the GPS system that reflects my continued personal concern and objection to the use of these units by Premiership players.

When this was first presented to me at the Injury Audit meeting in October 2009 I was not convinced at the value this unit has to preventing injury or to providing information which justifies the risks associated with allowing hard objects to be worn/strapped by players - and legislated against for all the time I have been involved in rugby at the highest level in both the pre-professional and the professional game. At the meeting I objected to the unit being worn by players, was shocked to learn that some players had already been wearing these harnessed units in Premiership games and was then disappointed to learn that there was an agreement in favour of the units by the medical contingent.

I accept the comments proffered by the very eminent Neurosurgeon Mr Nelson and the cadaveric research to look at Thoracic spine morbidity from impacts but these units are ill-fitted and in my opinion anatomically exposed to high impact injuries which would potentially pose a risk to the tackler and the tackled player. I feel it is equally our duty to predict, and to protect our players from, the potentials of injury which may otherwise be avoidable as well as to pay regard to the injuries which are unavoidable within the laws of the game. My concern is that this has the potential to serious injury and fact that it has not been retrospectively proven is because (legally) it has not been common practice thus far in game situations.

The position of the unit causes me concern given that the anatomical development in some players e.g. Front Row is more one of Thoracic kyphosis with little concavity between the Scapulae to house the unit. Impact injuries to the Thoracic spine does not stop at the possible fracture of the Spinous Process, it has implications for the Costovertebral joints, the emerging nerve roots and sinuvertebral nerves and more discreetly although sometimes more devastating, the autonomic Sympathetic Gangliae which are found along the paraspinal anatomy. Hard, and even more discreet plastics and malleable metals, are disallowed in supports and clothing for the very good reason of protecting the person wearing the support and the person in close contact (the tackler or indeed the player in direct contact purely from the nature of this being a contact sport). Impact to the plastic unit may also result in the shattering of the casing with the potential for a reasonably large shard of plastic which could pierce the harness, under garment, skin and deeper tissue, likewise it could pierce the harness, playing jersey and the skin of the tackler which could indeed be the scalp!

I believe that these hazardous outcomes are a potential in the game being played within the full spirit of the game but one must be sensitive to the fact that very rarely there may be the potential for foul-play, with an offending player being aware of the placement of a very hard object on another player.

Conversely to the above I accept that GPS has a valuable place within the game but in the training (non-contact) zone. In fact-finding conversations with Premiership players they agree that it provides data which is valuable to their personal development and to that of the team/squad in general. I further spoke with other patients of mine who are Premiership football players who were collectively very surprised when I asked them whether they wear the units in game-play, one indicated that when they wear the same harnessed units as the one's proposed in rugby the way they train-play is definitely hindered because the harnesses are uncomfortable and they are aware of the presence of these units.

If a consensus to support and agree to the inclusion of these units within play has been agreed by majorities on selective procedure and committees then it happens without my endorsement and my name must be removed from any document relating to the proposal unless it clearly states that I am NOT in favour of the inclusion. This correspondence must also be registered into archive if the proposal goes ahead.

My kindest regards

Kevin Lidlow, Medical Advisor to the RPA."

Appendix 3. Participant Consent Form

The Demands of Training and Playing in Elite Rugby Union

I have read and understand the information sheet provided with regards to the above study. All my questions have been answered to my satisfaction and I understand that I am free to ask for further information at any stage.

I am aware that:

1. My participation in the above study is entirely my choice.

2. I am free to withdraw from the study at any stage without giving any reason and without any prejudice incurred.

3. My insurance is not affected by taking part in the project.

4. The results of this project may be published but my anonymity will be preserved.

5. My individual data collected will under no circumstances be exchanged with any competitors from an opposing team or anyone other than the researcher and my club. The raw data that the results of the project depend on will be retained in secure storage for ten year and thereafter destroyed.

6. In the unlikely event of any grievances I understand that I may forward any complaints about the research process to Professor Sarah Andrew, Dean of the Faculty of Applied and Health Sciences, University of Chester, Parkgate Road, Chester, CH1 4BJ, 01244 513055.

Please enter (x) in the boxes provided where appropriate.

In both competitive matches and training I consent to:

Wearing a GPS unit ☐

To play with team mates wearing a GPS unit ☐

To play against opponents wearing a GPS unit ☐

…………………………………	…………………………………..	…./…./….
(Name of Participant)	**(Signature of Participant)**	**(Date)**
…………………………………	…………………………………..	…./…./….
(Name of Lead Researcher)	**(Signature of Lead Researcher)**	**(Date)**

Appendix 4. Tables of statistical differences

Appendix 4.1 Descriptive statistic differences of Vmax ($km \cdot h^{-1}$) by individual positions.

	Position	*n*	Positional Groups	Mean
1	Loosehead Prop	18	Front Row	gikmno
2	Hooker	12	Front Row	kno
3	Tighthead Prop	16	Front Row	giklmno
4	Left Lock	11	Second Row	kno
5	Right Lock	14	Second Row	ikmno
6	Blindside Flanker	13	Back Row	kn
7	Openside Flanker	13	Back Row	ac
8	Number 8	8	Back Row	kn
9	Scrum Half	15	Scrum Half	ace
10	Fly Half	11	Inside Back	kn
11	Left Wing	9	Outside Back	abcdefhj
12	Inside Centre	6	Inside Back	c
13	Outside Centre	13	Inside Back	ace
14	Right Wing	17	Outside Back	abcdefhj
15	Full Back	12	Outside Back	abcde

Significant differences (P≤0.05) denoted by a=Looshead Prop, b=Hooker, c=Tighthead Prop, d=Left Lock, e=Right Lock, f=Blindside Flanker, g=Openside Flankers, h=Number 8, i=Scrum Half, j=Fly Half k=Left Wing l=Inside Centre m=Outside Centre n=Right Wing o=Full Back

Appendix 4.2 Descriptive statistics differences of Vmax ($km \cdot h^{-1}$) by six positional groups.

Positional Groups	*n*	Mean
Front Row	46	cdef
Second Row	25	def
Back Row	34	af
Scrum Half	15	ab
Inside Backs	30	abf
Outside Backs	38	abce

Significant differences ($P \leq 0.05$) denoted by a=Front Row, b=Second Row, c=Back Row, d=Scrum Half, e=Inside Backs, f=Outside Backs

Appendix 4.3 Descriptive statistic differences of high intensity running (HIR) speed ($km{\cdot}h^{-1}$) and sprint speed ($km{\cdot}h^{-1}$) by individual position.

	Position	*n*	Positional Group	HIR Mean	Sprint Mean
1	Loosehead Prop	18	Front Row	gikmno	gikmno
2	Hooker	12	Front Row	kno	kno
3	Tighthead Prop	16	Front Row	fgiklmno	fgiklmno
4	Left Lock	11	Second Row	kno	kno
5	Right Lock	14	Second Row	ikmno	ikmno
6	Blindside Flanker	13	Back Row	ckn	ckn
7	Openside Flanker	13	Back Row	ac	ac
8	Number 8	8	Back Row	kn	kn
9	Scrum Half	15	Scrum Half	ace	ace
10	Fly Half	11	Inside Back	kn	kn
11	Left Wing	9	Outside Back	abcdefhj	abcdefhj
12	Inside Centre	6	Inside Back	c	c
13	Outside Centre	13	Inside Back	ace	ace
14	Right Wing	17	Outside Back	abcdefhj	abcdefhj
15	Full Back	12	Outside Back	abcde	abcde

Significant differences ($P \leq 0.05$) denoted by a=Looshead Prop, b=Hooker, c=Tighthead Prop, d=Left Lock, e=Right Lock, f=Blindside Flanker, g=Openside Flankers, h=Number 8, i=Scrum Half, j=Fly Half k=Left Wing l=Inside Centre m=Outside Centre n=Right Wing o=Full Back

Appendix 4.4 Descriptive statistic differences of high intensity running (HIR) speed ($km \cdot h^{-1}$) and sprint speed ($km \cdot h^{-1}$) by positional groups.

Positional Groups	*n*	HIR Mean	Sprint Speed Mean
Front Row	46	cdef	cdef
Second Row	25	def	def
Back Row	34	af	af
Scrum Half	15	ab	ab
Inside Backs	30	abf	abf
Outside Backs	38	abce	abce

Significant differences ($P \leq 0.05$) denoted by a=Front Row, b=Second Row, c=Back Row, d=Scrum Half, e=Inside Backs, f=Outside Backs

Appendix 4.5 Significant differences in total distance (m) when varying HIR speed classifications were applied to individual positions.

	Venter et al. (2011) (HIR 51 - 80% vMax)	Cunniffe et al. (2009) (HIR 18-20 km·h^{-1})	Eaton & George (2006) (HIR 14.4-25.2 km·h^{-1})	Roberts et al. (2008) (HIR 18-24.12 km·h^{-1})
	Mean	Mean	Mean	Mean
1	bcd	acd	abd	abc
2	bd	acd	bd	abc
3	bcd	acd	abd	abc
4	bd	acd	bd	abc
5	bd	acd	bd	abc
6	bd	acd	bd	abc
7	bcd	acd	abd	abc
8	bd	acd	bd	abc
9	bcd	acd	abd	abc
10	bcd	acd	abd	abc
11	bcd	acd	abd	abc
12	bcd	acd	abd	abc
13	bcd	acd	abd	abc
14	bcd	acd	abd	abc
15	bcd	acd	abd	abc

Significant differences denoted with a= Venter et al. (2011); b= Cunniffe et al. (2009); C= Eaton & George (2006) and d = Roberts et al. (2008)

Appendix 4.6 Significant differences in total distances (m) when varying sprint classifications were applied to individual positions.

Position	Venter et al. (2011) (>81% vMax)	Cunniffe et al. (2009) (>20km·h^{-1})	Eaton & George (2006) (>25.2km·h^{-1})	Roberts et al. (2008) (>24.12km·h^{-1})
	Mean	Mean	Mean	Mean
1	d	cd	bd	abc
2	d	cd	bd	abc
3		cd	bd	bc
4	bd	acd	bd	abc
5	b	acd	bd	bc
6	b	acd	bd	bc
7	b	acd	bd	bc
8	b	acd	bd	bc
9	b	acd	bd	bc
10	b	acd	bd	bc
11	bd	acd	bd	abc
12	b	acd	bd	bc
13	bd	acd	bd	abc
14	bd	acd	bd	abc
15	bd	acd	bd	abc

Significant differences denoted with a= Venter et al. (2011); b= Cunniffe et al. (2009); C= Eaton & George (2006) and d = Roberts et al. (2008)

Appendix 4.7 Significant differences in relative total distance (m·min^{-1}) in HIR when varying speed classifications were applied to individual positions.

	Venter et al. (2011) (HIR 51 - 80% vMax)	Cunniffe et al. (2009) (HIR 18-20km·h^{-1})	Eaton & George (2006) (HIR 14.4-25.2km·h^{-1})	Roberts et al. (2008) (HIR 18-24.12km·h^{-1})
	Mean	Mean	Mean	Mean
1	bcd	acd	abd	abc
2	bd	acd	bd	abc
3	bcd	acd	abd	abc
4	bd	acd	bd	abc
5	bcd	acd	abd	abc
6	bcd	acd	abd	abc
7	bcd	acd	abd	abc
8	bd	acd	bd	abc
9	bcd	acd	abd	abc
10	bcd	acd	abd	abc
11	bcd	acd	abd	abc
12	bcd	acd	abd	abc
13	bcd	acd	abd	abc
14	bcd	acd	abd	abc
15	bcd	acd	abd	abc

Significant differences denoted with a= Venter et al. (2011); b= Cunniffe et al. (2009); C= Eaton & George (2006) and d = Roberts et al. (2008)

Appendix 4.8 Significant differences in relative total distance ($m \cdot min^{-1}$) sprinting when varying speed classifications were applied to individual positions.

	Venter et al. (2011) Sprinting > 81% vMax	Cunniffe et al. (2009) (> 20km·h⁻¹)	Eaton & George (2006) (> 25.2km·h⁻¹)	Roberts et al. (2008) (>24.12km·h⁻¹)
	Mean	Mean	Mean	Mean
1	d	cd	bd	abc
2	b	acd	bd	bc
3	d	cd	bd	abc
4	bd	acd	bd	abc
5	bd	acd	b	ab
6	bd	acd	bd	abc
7	b	acd	bd	bc
8	b	acd	bd	bc
9	bd	acd	bd	abc
10	b	acd	bd	bc
11	bd	acd	bd	abc
12	b	acd	bd	bc
13	bd	acd	bd	abc
14	bd	acd	bd	abc
15	bd	acd	bd	abc

Significant differences denoted with a= Venter et al. (2011); b= Cunniffe et al. (2009); C= Eaton & George (2006) and d = Roberts et al. (2008)

Appendix 4.9 Significant differences in total distance (m) in HIR when varying speed classifications were applied to six positional groups.

Positional Group	Venter et al. (2011) (HIR 51 - 80% vMax)	Cunniffe et al. (2009) (HIR 18-20km·h^{-1})	Eaton & George (2006) (HIR 14.4-25.2km·h^{-1})	Roberts et al. (2008) (HIR 18-24.12km·h^{-1})
	Mean	Mean	Mean	Mean
Front Row	bcd	acd	abd	abc
Second Row	bcd	acd	abd	abc
Back Row	bcd	acd	abd	abc
Scrum Half	bcd	acd	abd	abc
Inside Backs	bcd	acd	abd	abc
Outside Backs	bcd	acd	abd	abc

Significant differences denoted with a= Venter et al. (2011); b= Cunniffe et al. (2009); C= Eaton & George (2006) and d = Roberts et al. (2008)

Appendix 4.10 Significant differences in total distance (m) sprinting when varying speed classifications were applied to six positional groups.

Positional Group	Venter et al. (2011) Sprinting > 81% vMax	Cunniffe et al. (2009) (> 20km·h^{-1})	Eaton & George (2006) (> 25.2km·h^{-1})	Roberts et al. (2008) (>24.12km·h^{-1})
	Mean	Mean	Mean	Mean
Front Row	bd	acd	bd	abc
Second Row	bd	acd	bd	abc
Back Row	b	acd	bd	bc
Scrum Half	bd	acd	bd	abc
Inside Backs	bd	acd	bd	abc
Outside Backs	bd	acd	bd	abc

Significant differences denoted with a= Venter et al. (2011); b= Cunniffe et al. (2009); C= Eaton & George (2006) and d = Roberts et al. (2008)

Appendix 4.11 Significant differences in relative total distance (m·min^{-1}) in HIR when varying speed classifications were applied to positional groups.

Positional Group	Venter et al. (2011) (HIR 51 - 80% vMax)	Cunniffe et al. (2009) (HIR 18-20km·h^{-1})	Eaton & George (2006) (HIR 14.4-25.2km·h^{-1})	Roberts et al. (2008) (HIR 18-24.12km·h^{-1})
	Mean	Mean	Mean	Mean
Front Row	bcd	acd	abd	abc
Second Row	bcd	acd	abd	abc
Back Row	bcd	acd	abd	abc
Scrum Half	bcd	acd	abd	abc
Inside Backs	bcd	acd	abd	abc
Outside Backs	bcd	acd	abd	abc

Significant differences denoted with a= Venter et al. (2011); b= Cunniffe et al. (2009); C= Eaton & George (2006) and d = Roberts et al. (2008)

Appendix 4.12 Significant differences in relative total distance (m·min^{-1}) sprinting when varying sprinting classifications were applied to positional groups.

Positional Group	Venter et al. (2011) Sprinting > 81% vMax	Cunniffe et al. (2009) (> 20km·h^{-1})	Eaton & George (2006) (> 25.2km·h^{-1})	Roberts et al. (2008) (>24.12km·h^{-1})
	Mean	Mean	Mean	Mean
Front Row	bd	acd	bd	abc
Second Row	bd	acd	bd	abc
Back Row	b	acd	bd	abc
Scrum Half	bd	acd	bd	abc
Inside Backs	bd	acd	bd	abc
Outside Backs	bd	acd	bd	abc

Significant differences denoted with a= Venter et al. (2011); b= Cunniffe et al. (2009); C= Eaton & George (2006) and d = Roberts et al. (2008)

Appendix 4.13 Significant differences in locomotive movement of six positional groups.

Position	Front Row (*n*=103)	Second Row (*n*=76)	Back Row (*n*=95)	Scrum Half (*n*=46)	Inside Backs (*n*=132)	Outside Backs (*n*=136)
Time (min)	bcef	a	a	ef	adf	ad
Total Distance (m)	bcdef	acdef	abde	abcf	abcf	abde
Relative Total Distance ($m \cdot min^{-1}$)	cdef	cdef	abde	abcef	abcdf	abde
Maximum Speed	cdef	cdef	abef	abf	abcf	abcde
Average Speed	d	cde	b	abe	bdf	ce
TD at Vmax						
TD < 20% of Vmax	bcdef	acdef	abdef	abcf	abcf	abcde
TD 20 - 50% of Vmax	cdef	df	adf	abce	adf	abce
TD 51 - 80% of Vmax	ce	c	abf		af	ce
TD 81 - 95% of Vmax	cef	cf	abd	cef	ad	abd
TD 96 - 100% of Vmax						
% TD at Vmax						
% TD < 20% of Vmax	cdef	cdef	abdef	abcef	abcdf	abcde
% TD 20 - 50% of Vmax	cdef	def	aef	abef	abcdf	abcde
% TD 51 - 80% of Vmax	f	f	ef	f	ce	abcde
% TD 81 - 95% of Vmax	cf	cf	abd	ce	d	ab
% TD 96 - 100% of Vmax						

Significant differences denoted as a=Front Row; b= Second Row; c= Back Row; d=Scrum Half; e = Inside Backs; f = Outside Backs.

Appendix 4.14 Significant differences in locomotive movement descriptors of individual positions (1-5).

Position Distances	Loosehead Prop (*n*=31)	Hooker (*n*=33)	Tighthead Prop (*n*=39)	Left Lock (*n*=27)	Right Lock (*n*=49)
Total Distance (m)	afgijklmno	ijlmno	aefghijklmno	cijlmo	cfgijklmno
Relative Total Distance ($m \cdot min^{-1}$)	ijlmo	ij	fgijlmno	gijlmno	ijlmo
Maximum Speed ($km \cdot h^{-1}$)	fijklmno	gikmno	fgijklmno	gijklmno	fgijklmno
Average Speed ($km \cdot h^{-1}$)	c	cdn	abfgilm	bfgilm	i
Total Distance at Vmax					
TD < 20% of Vmax (m)	dfghijklmno	fghijklmno	dfghijklmno	aijklmno	fgijklmno
TD 20 - 50% of Vmax (m)	ckn		aefgijlm	n	ckn
TD 51 - 80% of Vmax (m)	c		afgijl		
TD 81 - 95% of Vmax (m)	cjn	gjkn	agjkn	jn	N
TD 96 - 100% of Vmax (m)					
% Total Distance at Vmax					
% TD < 20% of Vmax (%)	dfghijklmno	gijklmno	iklmno	aklmno	ijklmno
% TD 20 - 50% of Vmax (%)	dfgijklmno	fgijklmno	fgijklmno	ajklmno	fgijklmno
% TD 51 - 80% of Vmax (%)	kmno			kn	
% TD 81 - 95% of Vmax (%)		n	n	n	
% TD 96 - 100% of Vmax (%)					

Significant difference denoted as a = Loosehead Prop; b = Hooker; c = Tighthead Prop; d = Left Lock; e = Right Lock; f = Blindside Flanker; g = Openside Flanker; h = Number 8; I = Scrum Half; j = Fly Half; k = Left Wing; l = Inside Centre; m = Outside Centre; n=Right Wing; o = Full Back.

Appendix 4.15 Significant differences in locomotive movement descriptors of individual positions (6-10).

Position Distances	Blindside Flanker (*n*=37)	Openside Flanker (*n*=45)	Number 8 (*n*=13)	Scrum Half (*n*=46)	Fly Half (*n*=24)
Total Distance (m)	ace	acei	c	abcdeg	abcdek
Relative Total Distance ($m \cdot min^{-1}$)	ci	cdi	i	abcdefghkmno	abcde
Maximum Speed ($km \cdot h^{-1}$)	abckmno	abcdekmno	kmno	abcdekn	acdekmno
Average Speed ($km \cdot h^{-1}$)	cdn	cd	i	cdehjkno	i
TD at Vmax					
TD < 20% of Vmax (m)	abceijklmno	abceijklmno	abcklmno	abcdefgno	abcdefgkno
TD 20 - 50% of Vmax (m)	ckn	dkn		ckmno	ckn
TD 51 - 80% of Vmax (m)	ckn	ck		c	ck
TD 81 - 95% of Vmax (m)		bci		jkno	abcd
TD 96 - 100% of Vmax (m)					
% TD at Vmax					
% TD < 20% of Vmax (%)	aklmno	abklmno	akmno	abcekmno	abekno
% TD 20 - 50% of Vmax (%)	abcekmno	abcekmno	kno	abcekmno	abcdekno
% TD 51 - 80% of Vmax (%)	kmno	kno			
% TD 81 - 95% of Vmax (%)	i	i		fgjkno	i
% TD 96 - 100% of Vmax (%)					

Significant difference denoted as a = Loosehead Prop; b = Hooker; c = Tighthead Prop; d = Left Lock; e = Right Lock; f = Blindside Flanker; g = Openside Flanker; h = Number 8; I = Scrum Half; j = Fly Half; k = Left Wing; l = Inside Centre; m = Outside Centre; n=Right Wing; o = Full Back.

Appendix 4.16 Significant differences in locomotive movement descriptors of individual positions (11-15).

Position Distances	Left Wing (*n*=47)	Inside Centre (*n*=38)	Outside Centre (*n*=70)	Right Wing (*n*=49)	Full Back (*n*=40)
Total Distance (m)	acej	abcde	abcde	abce	abcde
Relative Total Distance ($m \cdot min^{-1}$)	i	acde	acdei	cdi	acdei
Maximum Speed ($km \cdot h^{-1}$)	abcdefghijl	acdekmno	abcdefghjl	abcdefghijl	abcdefghjl
Average Speed ($km \cdot h^{-1}$)	i	cd	cd	bfi	I
TD at Vmax					
TD < 20% of Vmax (m)	abcdefghj	abcdefghno	abcdefgho	abcdefghijl	abcdefghijlm
TD 20 - 50% of Vmax (m)	aefgijlm	cn	cin	adefgijlm	I
TD 51 - 80% of Vmax (m)	fgjl	ckn		fl	
TD 81 - 95% of Vmax (m)	bc			abcde	
TD 96 - 100% of Vmax (m)					
% TD at Vmax					
% TD < 20% of Vmax (%)	abcdefghijlm	abcdefgkno	abcdefghikno	abcdefghijlm	abcdefghijlm
% TD 20 - 50% of Vmax (%)	abcdefghijlm	abcdekno	abcdefgikno	abcdefghijlm	abcdefgijlm
% TD 51 - 80% of Vmax (%)	adfgl	kn	af	adfgl	afg
% TD 81 - 95% of Vmax (%)	i	n		bcdil	I
% TD 96 - 100% of Vmax (%)					

Significant difference denoted as a = Loosehead Prop; b = Hooker; c = Tighthead Prop; d = Left Lock; e = Right Lock; f = Blindside Flanker; g = Openside Flanker; h = Number 8; I = Scrum Half; j = Fly Half; k = Left Wing; l = Inside Centre; m = Outside Centre; n=Right Wing; o = Full Back.

Appendix 4.17 Significant differences in average frequencies in key performance indicators between six positional groups.

Indicator	Front Row (*n*=93)	Second Row (*n*=69)	Back Row (*n*=84)	Scrum Half (*n*=36)	Inside Backs (*n*=126)	Outside Backs (*n*=116)
Ball Carries	bcef	ad	a	bef	ad	ad
Ball Carries into contact	bcef	ad	ad	bcef	ad	ad
Ball Carries &Try scored	f	f	f			abc
Passes	bcef	adef	adef	bcef	abcdf	abcde
Kicks	def	def	def	abcef	abcd	abcd
Tackles Made	cdf	cdf	abdef	abce	cdf	abce
Tackles Missed						
Total Rucks	def	def	def	abcef	abcdf	abcde
Contested Rucks	def	def	def	abcef	abcd	abcd
Turnover Lost	cdef	ef	aef	a	abc	abc
Penalty Conceded			e		c	
Total Scrum	bdef	def	def	abc	abc	abc
Own Lineout Lifter	def	cdef	bdef	abc	abc	abc
Own Lineout Caught	def	cdef	bdef	abc	abc	abc
Static Exertions	bcdef	a	adef	abcef	acdf	acde
Static Exertions Duration	def	def	def	abcef	abcd	abcd
% of Ball in Play in Static Exertion	def	def	def	abcef	abcd	abcd
High Intensity Exercise Bouts (HIEB)	cdef	cdef	abdef	abc	abc	abc

Significantly different from a = Front Row, b = Second Row, c = Back Row, d = Scrum Half, e = Inside Backs, f = Outside Backs

Appendix 4.18 Significant differences in average team percentage between six positional groups.

Indicator	Front Row (*n*=93)	Second Row (*n*=69)	Back Row (*n*=84)	Scrum Half (*n*=36)	Inside Backs (*n*=126)	Outside Backs (*n*=116)
Team Ball Carries	bcef	a	a	ef	ad	ad
Team Ball Carries Try & scored	f		f			
Passes	bcdef	ade	adef	abcef	abcdf	acde
Kicks	def	de	def	abcef	abcd	acd
Tackles Made	cdf	cde	abdef	abce	bcdf	ace
Tackles Missed						
Total Rucks	def	de	def	abcef	abcdf	acde
Contested Rucks	cdef	d	d	abcef	ad	ad
Turnover Lost	cdef	e	aef	a	abc	ac
Penalty Conceded						
Own Lineout Caught	def	cde	bdef	abc	abc	ac
Own Lineout Lifter	def	cde	bdef	abc	abc	ac

Significantly different from a = Front Row, b = Second Row, c = Back Row, d = Scrum Half, e = Inside Backs, f = Outside Backs

Appendix 4.19 Significant differences in average frequencies in key performance indicators between individual positions (1 – 5).

Indicator	Loosehead Prop (1) (*n*=30)	Hooker (2) (*n*=32)	Tighthead Prop (3) (*n*=31)	Left Lock (4) (*n*=24)	Right Lock (5) (*n*=45)
Ball Carries	hlmo	hlmo	ehklmo		c
Ball Carries into contact	ho	hlo	hlmo	i	i
Ball Carries &Try scored	kn				
Pass	ijlmno	ilmno	gijlmno	ijlo	ijlo
Kick	ijklno	ilno	ijklmno	ijkno	ijklmno
Tackles Made	fgno	ckno	bfgo	ikno	gikno
Tackles Missed					
Total Rucks	ijkmno	lmno	ijklmno	eijklmno	dijklmno
Contested Rucks	ijklmno	lmno	dgijklmno	cijklmno	ijklmno
Turnover Lost	ijklmn	m	klmno		m
Penalty Conceded	no				
Total Scrum	ijklmno	dlmno	dijklmno	bcijklmno	ijklmno
Own Lineout Lifter	bijklmno	acdeflmno	bijklmno	bghijklmno	bijklmno
Own Lineout Caught		cdefghijklmno	bdef	bcijklmno	bcho
Static Exertions	ijklmno	dfglmno	dfgijklmno	abcefgijklmno	dijklmno
Static Exertions Duration	ijklmno	lmno	dijklmno	cijklmno	ijklmno
% of Ball in Play in Static Exertion	ijklmno	lmno	ijklmno	ijklmno	ijklmno
High Intensity Exercise Bouts (HIEB)	gijkmno	gijklmno	gijkmno	ijklmno	gijklmno

Significantly different from a = Loosehead Prop, b = Hooker, c = Tighthead Prop, d = Left Lock, e = Right Lock, f = Blindside Flanker, g = Openside Flanker, h = Number 8, i= Scrum Half, j= Fly Half, k = Left Wing, l = Inside Centre, m = Outside Centre, n = Right Wing, o = Full Back

Appendix 4.20 Significant differences in average frequencies in key performance indicators between individual positions (6 –10).

Indicator	Blindside Flanker (6) (*n*=30)	Openside Flanker (7) (*n*=42)	Number 8 (8) (*n*=12)	Scrum Half (9) (*n*=36)	Fly Half (10) (*n*=24)
Ball Carries	i	lo	abci	fklo	o
Ball Carries into contact	i	io	aic	dfgkio	o
Ball Carries &Try scored					klmno
Passes	ijlmo	cjlmo	ij	abcdefjklmn	acdefghiklmno
Kicks	ijklno	ijlmo	ijo	abcdefgjklmn	acdefghiklmno
Tackles Made	aceikmno	aceiklmno	ikmo	defgjlo	ikno
Tackles Missed					
Total Rucks	ijklmno	ijklmno	ijklmno	acdefgklmno	acdefghilm
Contested Rucks	ijklmno	cijklmno	ijklmno	acdefgklmno	acdefgh
Turnover Lost				a	a
Penalty Conceded		m			
Total Scrum	ijklmno	ijklmno	ijklmno	acdefg	acdefgh
Own Lineout Lifter	bijklmno	dijklmno	dijklmno	acdefg	adefgh
Own Lineout Caught	bcijklmno	bijklmno	beiklmno	bdfg	bdfgh
Static Exertions	cdbijklmno	bcdijklmno	ijklmno	acdefgklmn	acdefghino
Static Exertions Duration (s)	ceijklmno	ijklmno	ijklmno	acdefgklmno	adefghi
% of Ball in Play in Static Exertion	ijklmno	ijklmno	ijklmno	acdefgklmno	acdefghlm
High Intensity Exercise Bouts (HIEB)	ijklmno	abcijklmno	ijklmno	abcdefgh	abcdefgh

Significantly different from a = Loosehead Prop, b = Hooker, c = Tighthead Prop, d = Left Lock, e = Right Lock, f = Blindside Flanker, g = Openside Flanker, h = Number 8, i= Scrum Half, j= Fly Half, k = Left Wing, l = Inside Centre, m = Outside Centre, n = Right Wing, o = Full Back

Appendix 4.21 Significant differences in average frequencies in key performance indicators between individual positions (11 – 15).

Indicator	Left Wing (11) (*n*=40)	Inside Centre (12) (*n*=37)	Outside Centre (13) (*n*=65)	Right Wing (14) (*n*=42)	Full Back (15) (*n*=34)
Ball Carries	aci	abcij	abci	ci	abcgij
Ball Carries into contact	i	bci	ci	io	abcgij
Ball Carries &Try scored	a			a	
Passes	ijlo	abcdefijk	abcfgij	abcfij	abcdefgijk
Kicks	acdefij	abcefij	cegijko	abcdefhijm	abcdefghijklm
Tackles Made	efghjlmo	gikno	fgikno	abdefghjlm	abcdefghijklm
Tackles Missed		o			l
Total Rucks	acdefghij	bcdefghij	abcdefghijn	abcdefghilm	abcdefghi
Contested Rucks	acdefghi	abcdefghij	abcdefghijn	abcdefghilm	abcdefghi
Turnover Lost	ac	ac	abce	ac	c
Penalty Conceded			g	agh	a
Total Scrum	acdefgh	abcdefgh	abcdefgh	abcdefgh	abcdefgh
Own Lineout Lifter	acdefgh	abcdefgh	abcdefgh	abcdefgh	abcdefgh
Own Lineout Caught	bdfgh	bdfgi	bdfgh	bfdg	bdefgh
Static Exertions	acdefglmn	abcdefg	abcdefgno	abcdefg	abcdefg
Static Exertions Duration	adefgn	abdefg	abdefgn	abdef g	abdefg
% of Ball in Play in Static Exertion	acdefgn	abcdefg	abcdfegn	abcdefg	acdefg
High Intensity Exercise Bouts (HIEB)	abcdefgh	bdefghn	abcdefgh	abcdefghi	abcdefgh

Significantly different from a = Loosehead Prop, b = Hooker, c = Tighthead Prop, d = Left Lock, e = Right Lock, f = Blindside Flanker, g = Openside Flanker, h = Number 8, i= Scrum Half, j= Fly Half, k = Left Wing, l = Inside Centre, m = Outside Centre, n = Right Wing, o = Full Back

Appendix 4.22 Significant differences in average percentage of total team efforts between individual positions (1 – 5).

Indicator	Loosehead Prop (1) (*n*=30)	Hooker (2) (*n*=32)	Tighthead Prop (3) (*n*=31)	Left Lock (4) (*n*=24)	Right Lock (5) (*n*=45)
Ball Carries	l	lmo	hklmo	lo	O
Ball Carries & Try scored	k				
Passes	hijlmno	ijlmno	ijlmno	ijlo	ijlmo
Kicks	ijklno	ijklno	ijklno	ijkno	ijklmno
Tackles Made	fgino	cikno	bdfg	cikmno	gikno
Tackles Missed	i				
Total Rucks	ijklmno	ijklmno	ijklmno	ijklmno	ijklmno
Contested Rucks		ci	befghklmno	i	ci
Turnover Lost	gijklmno		klmno	km	mo
Penalty Conceded					
Own Lineout Caught		cdefghijn	b	bijklmno	bghijklmno
Own Lineout Lifter	ijmno	cdefijklmno	bijklmno	bijklmno	bijklmno

Significantly different from a = Loosehead Prop, b = Hooker, c = Tighthead Prop, d = Left Lock, e = Right Lock, f = Blindside Flanker, g = Openside Flanker, h = Number 8, i= Scrum Half, j= Fly Half, k = Left Wing, l = Inside Centre, m = Outside Centre, n = Right Wing, o = Full Back

Appendix 4.23 Significant differences in average percentage of total team efforts between individual positions (6 – 10).

Indicator	Blindside Flanker (6) (*n*=30)	Openside Flanker (7) (*n*=42)	Number 8 (8) (*n*=12)	Scrum Half (9) (*n*=36)	Fly Half (10) (*n*=24)
Ball Carries	lo	o	ci	hklmo	
Ball Carries & Try scored					
Passes	ijlmo	ijlmo	aij	abcdefgihjklmno	abcdegihlmo
Kicks	ijklno	ijklno	o	abcdefgijklmn	abcdefgklmno
Tackles Made	acikmno	aceijklmno	eijno	abdefghjlmo	ghino
Tackles Missed				a	
Total Rucks	ijklmno	ijklmno	eijkmno	abcdefghijklmno	abcdefghilmo
Contested Rucks	ci	ci	c	bdefgklmo	
Turnover Lost		a		a	a
Penalty Conceded			ino	h	
Own Lineout Caught	bijklmno	bijklmno	beiklmno	bdefgh	bdefg
Own Lineout Lifter	bijklmno	ijklmno	ijklmno	abcdefgh	abcdefgh

Significantly different from a = Loosehead Prop, b = Hooker, c = Tighthead Prop, d = Left Lock, e = Right Lock, f = Blindside Flanker, g = Openside Flanker, h = Number 8, i= Scrum Half, j= Fly Half, k = Left Wing, l = Inside Centre, m = Outside Centre, n = Right Wing, o = Full Back

Appendix 4.24 Significant differences in average percentage of total team efforts between individual positions (11 - 15).

Indicator	Left Wing (11) (*n*=40)	Inside Centre (12) (*n*=37)	Outside Centre (13) (*n*=65)	Right Wing (14) (*n*=42)	Full Back (15) (*n*=34)
Ball Carries	ci	abcdfi	abci		bcdefgin
Ball Carries & Try scored	a				
Passes	ilo	abcdefgij	abcefgij	abcfi	abcdefgijk
Kicks	abcdefgijo	abcefgijo	egijko	abcdefgijo	abcdefghjklmn
Tackles Made	bdefglo	gikno	dfgikno	abdefghjlm	abdefghijklm
Tackles Missed					l
Total Rucks	abcdefghi	abcdefgijn	abcdefghijn	abcdefghilm	abcdefghij
Contested Rucks	ci	ci	ci	c	ci
Turnover Lost	acd	ac	abcdef	ac	ace
Penalty Conceded	g			h	h
Own Lineout Caught	defgh	defgh	defgh	bdefgh	defgh
Own Lineout Lifter	bcdefgh	bcdefgh	abcdefgh	abcdefgh	abcdefgh

Significantly different from a = Loosehead Prop, b = Hooker, c = Tighthead Prop, d = Left Lock, e = Right Lock, f = Blindside Flanker, g = Openside Flanker, h = Number 8, i= Scrum Half, j= Fly Half, k = Left Wing, l = Inside Centre, m = Outside Centre, n = Right Wing, o = Full Back

Appendix 5: Raw SPSS Data Files

As arranged on the disc supplied